NPS-SE-08-003

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Hybrid Airship Multi-Role (HAMR)
Anti-Submarine Warfare (ASW) Mission Capability

by

Keyport MSSE Cohort

20 June 2008

Approved for public release; distribution is unlimited

Prepared for Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

This report was prepared for the Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering.

This report was prepared by the Masters of Science in Systems Engineering (MSSE) Cohort (Number) from the Naval Undersea Warfare Command Division Keyport:

Authors:
Agpaoa, Roy
Cawley, Matthew
Cossey, Chad
Galvan, Jose
Giang, Alan
Hanchinamani, Joseph
Ikeda, Jeffrey
Kenney, John
Magnusson, Lance
Martinez, Christopher
Newberry, Mike
Raymond, Eldridge
Rykala, John
Watts, Jason
Wood, Micheal

Reviewed by:

E.P. Paulo, Ph. D.
Project Advisor

David H. Olwell, Ph. D.
Chairman, Department of Systems Engineering

Released by:

M.M. Rhoades
Project Advisor

Dan C. Boger, Ph. D.
Interim Vice President and
Dean of Research

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2008	**3. REPORT TYPE AND DATES COVERED** Technical Report

4. TITLE AND SUBTITLE: Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission

5. FUNDING NUMBERS

6. AUTHOR(S)
Agpaoa, Roy
Cawley, Matthew
Cossey, Chad
Galvan, Jose
Giang, Alan
Hanchinamani, Joseph
Ikeda, Jeffrey
Kenney, John
Magnusson, Lance
Martinez, Christopher
Newberry, Mike
Raymond, Eldridge
Rykala, John
Watts, Jason
Wood, Micheal

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES: The views expressed in this report are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT	**12b. DISTRIBUTION CODE**
Approved for public release; distribution is unlimited	A

13. ABSTRACT (maximum 200 words)
The Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Module project applies established systems engineering principles and processes to the design of an ASW payload module that examines the capability of the HAMR to perform persistent ASW mission support. Critical system functions and objectives are identified and are assigned appropriate quantitative metrics. Additionally, three alternative architectures are generated and evaluated using the appropriate metrics based on results from modeling using Naval Systems Simulation (NSS). Manning is considered as a key stakeholder parameter and is included as an evaluation concern. The alternatives are also compared through the examination of life cycle costs. The recommendation to the stakeholders based on the research and results is an unmanned ASW sensor platform that uses other ASW assets for prosecution.

14. SUBJECT TERMS
Anti-submarine Warfare, Hybrid Airship, Unmanned ASW Sensors, Systems Engineering, Simulation, Naval System Simulation (NSS)

15. NUMBER OF PAGES 196

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Module project applies established systems engineering principles and processes to the design of an ASW payload module that examines the capability of the HAMR to perform persistent ASW mission support. Critical system functions and objectives are identified and are assigned appropriate quantitative metrics. Additionally, three alternative architectures are generated and evaluated using the appropriate metrics based on results from modeling using Naval Systems Simulation (NSS). Manning is considered as a key stakeholder parameter and is included as an evaluation concern. The alternatives are also compared through the examination of life cycle costs. The recommendation to the stakeholders based on the research and results is an unmanned ASW sensor platform that uses other ASW assets for prosecution.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENTS

The NUWC Keyport Cohort would like to acknowledge and extend our heartfelt gratitude to the following persons who have made the completion of our Masters of Science in Systems Engineering Capstone Project possible:

Dr. Eugene Paulo, Advisor, Department of Systems Engineering, for the constant reminders and much needed motivation.

Mr. Mark Rhoades, Advisor, Department of Systems Engineering, for the constant reminders and much needed motivation especially with Naval Simulation System (NSS) support.

Mr. Phil Forsythe, Lockheed Martin Company, for assistance, guidance, and support with developing models and scenarios in NSS software.

Most especially to our family and friends.

EXECUTIVE SUMMARY

Overview

The Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Module project applies established systems engineering principles and processes to the design of an ASW payload module that examines the capability of the HAMR to perform persistent ASW mission support. The concept of an ASW module was born out of discussion with the HAMR stakeholders, which includes COCOM commanders. The concept of the ASW module is to provide the Navy with a new and unique or transformational means to conduct ASW. While the ASW module is hosted by the airship, the airship is not within the scope of the research paper.

The large lift variant of the HAMR is expected to lift 1,000 tons, and with scalable technology, a variant capable of 50 ton capacity is being considered for development. This smaller airship's lift appears suitable for missions other than heavy lifting such as ASW. A hybrid airship has an exceptional "time in air" or loitering capability, which makes it an attractive platform for the moving of materials or as a platform for a weapons systems. It can fly over water or land at speeds up to 100 knots allowing it to take a more direct route to its destination. Its ability to economically loiter offers obvious advantages for a surveillance platform. This module and airship combination merges existing capabilities from the submarine, surface ship, rotary wing, and fixed wing aircraft in a single ASW mission module. That mission module, carried by the hybrid airship, can remain on station and provide 24-7 surveillance for periods exceeding 10 days.

The research and analysis used for the research follows the prescribed process defined by the Department of Defense acquisition reform act. A number of specific systems engineering models, methods, and processes are utilized as part of this research. Based on detailed and thorough input from a large group of stakeholders, critical system functions and objectives are identified and are assigned appropriate quantitative metrics. To properly frame these functions, a realistic and relevant set of scenarios are developed and vetted by our key stakeholders. Additionally, three alternative architectures are generated and evaluated using the appropriate metrics. All alternatives are quantitatively

assessed using the Naval System Simulation (NSS), and a cost benefit and analysis was performed to support the best case alternative selection.

System Functions

Based on input from a variety of stakeholders, the following functions were determined to be fundamental to our systems engineering design:

Detect: This is the ability of the proposed system to search a specified area and detect the presence of enemy submarines in that area.

Classify: This is the ability of the proposed system to identify detected submarines correctly.

Engage: This is the ability of the proposed system to terminate or alter the mission of known enemy submarines.

Track: This is the ability of the system to effectively maintain an accurate track on an enemy target.

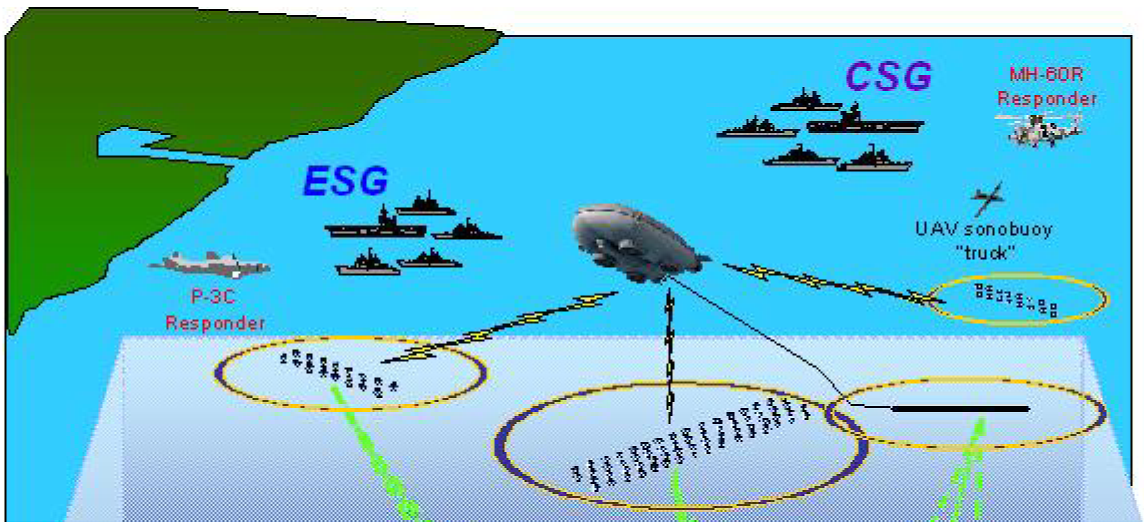
Localize: This is the ability of the system to reduce the area of uncertainty of the location of the submarine sufficiently to engage the submarine.

Communicate: This is the ability of the system to effectively and reliably communicate with own force and allies.

Detection can be broken down into sub-functions including queuing, search plan (surface & subsurface), environmental planning, surveillance, and loitering. Sub-functions of communications include battle group connectivity, airframe and pilot communications, over the horizon relay, receiving intelligence, and data transmission. The engage function includes the sub-functions to destroy, disable, deceive, or deter. Tracking encompasses the sub-functions of data collection, maintain contact, observe, and report. Classify includes data processing, data comparison, determination of contact (friend or foe), and the determination of threat level. Localizing a threat has sub-functions of positioning of friend or foe and determining a fire solution.

Scenarios

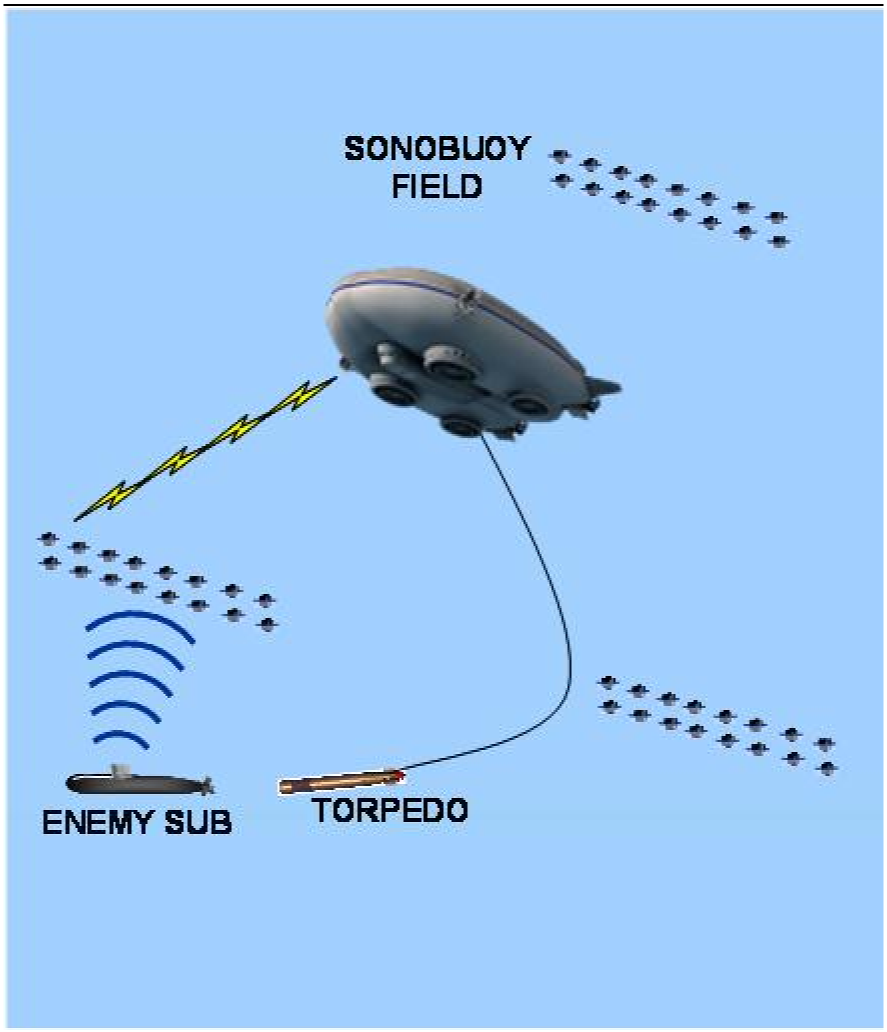
The HAMR ASW module is considered in two operational scenarios: stand alone patrol and maintaining a safe operating area for a CSG. The module provides such support by effectively executing its ASW functions as depicted in the figure below.



HAMR Tactical ASW Concept of Operations

Stand Alone Patrol

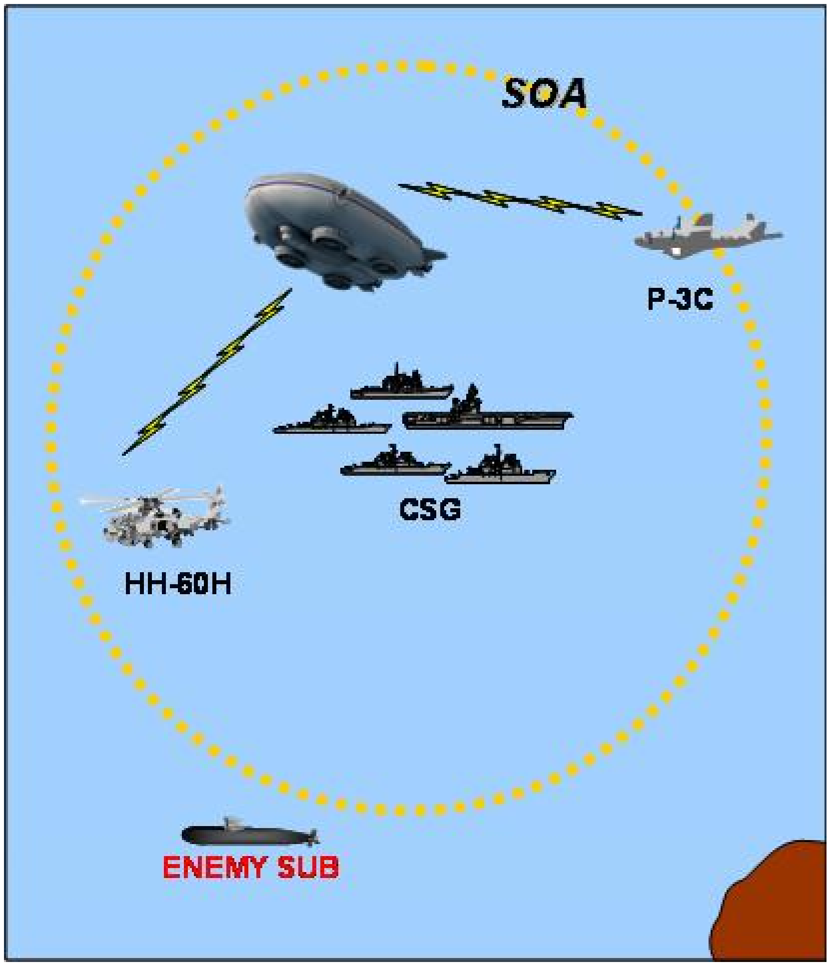
The HAMR, equipped with the ASW module, may be used as a single patrol asset against open water or confined threat areas. This would be accomplished by having the HAMR module strategically deploy and monitor sonar sensors. The module would actively process the data returned by the sensors allowing the HAMR to aggressively pursue, track, and engage all unidentified submarine contacts. Other ASW assets may be alerted with the modules ability to communicate with various platforms if the situation calls for alternate types of engagement or means to alter the threats' course of action.



Stand Alone Patrol Concept of Operations

Safe Operating Area

The HAMR ASW module may also be used to maintain a safe operating area (SOA) for a CSG or ESG (see figure below). The ASW module would act as a communications hub for all other assets allowing strategic planning using real-time data passed between the module and additional assets. The module would be capable of deploying and monitoring sensors within a certain radius, sharing any detections and tracks as a result of the data returned by the sensors. This application would ensure no enemy submarines could intercept forces within the SOA. Upon detection of a threat the module would be equipped to engage or have an alternate asset execute the engagement.



Safe Operating Area Concept of Operations

Alternatives

There are three alternative architectures assessed in this report. The first alternative offers sensing and surveillance as well as engagement capabilities. These capabilities include lightweight torpedoes, super-cavitating munitions weapon, and air dropped munitions, which can either have contact or proximity fusing options. Sensing includes an electro-optical infrared (EO/IR) camera, water penetrating laser detecting and ranging (LIDAR), magnetic anomaly detection (MAD), electronic surveillance receivers, surface search radar, and a payload of sonobuoys to provide acoustic monitoring all day for up to 10 days. It is crewed with four onboard watch standers per shift. The second

alternative provides no organic sub-surface engagement capability but relies on outside support from the P-3 community for this capability. In lieu of the engagement capability, it adds enhanced sensing capability with the addition of a thin line towed array, dipping sonar, and a side aperture array sonar and is crewed with four watch standers per shift. The third alternative does not provide organic sub-surface engagement and also relies on outside engagement from the P-3 community. It has the potential for an exceptionally lengthy loiter period, limited only to the airship's ability to remain airborne and is unmanned. It requires two remote ground operators as crew. All three alternatives provide full communications, the ability to render and remotely share any and all sensor data, to export a common operating picture (COP).

Risk

Some of the technology recommended in the ASW module has never before been operated on an airborne platform. Alternative 2 applies the use of a thin line towed array. While this system is currently used in both shipboard and submarine applications, the use of this system in an aerial vehicle is unproven. This application has been discussed with many subject matter experts (SMEs) who believe the process can be successfully achieved technically; however it affords a higher level of risk. The balance of the technology selected is adapted from other airborne platforms and is currently fielded hence presents marginal risk in application to an ASW airship platform.

Conclusions and Recommendations

After review of the alternatives, all three meet the stakeholders' minimum requirements for the HAMR ASW mission module. After detailed analysis of the modeling data, however, it becomes apparent the unmanned module, Alternative 3, provides the best performance against submarines under the associated scenarios. That is in part from its extensive sonobuoy capacity and the utilization of agile P-3 aircraft as its means to engage the targets. The modeling data clearly shows in the barrier scenario the HAMR ASW module carrying more sonobuoys has shorter time to detect than either a single P-3 or the other HAMR ASW module configurations. Due to the importance

placed on barrier protection in the modeling scenario, the HAMR was less effective than the P-3 in prosecution. In the given barrier scenario, however, the HAMR ASW solutions that direct P-3s for prosecution provide a statistically significant force multiplier. Based on these modeling findings, Alternative 3, HAMR ASW module is the better effective force multiplier.

Manning was a key factor in the value structure defined by the stakeholders. With the Navy's trend toward reducing manpower, new weapon systems must address the lower manning preference. In a comparison of manning to the P-3, all three HAMR ASW mission module alternatives require less manning. Alternative 1 requires four watch standers. Alternative 2 also requires a crew of four while Alternative 3 only requires two operators in a remote station for ASW.

When comparing costs, Alternative 1 has a life cycle cost of $50.4M per unit over its expected 25 year life expectancy. Alternative 2 $68.8M each over the same period and Alternative 3 is the lowest cost alternative at $44.4M.

In assessing risk, many of the systems used in Alterative 1 have previously been integrated into the P-3 and offer a minimum of risk. Inserting new technology in the form of the Tactically Integrated Sensors (TIS) combat system into a unique airborne application like Alternative 1 yields medium risk. While TIS is fielded on all of the Navy's aircraft carriers, it has not been applied to an airborne environment. Alternative 2 applies the use of a thin line towed array which is currently used in both shipboard and submarine applications, but airborne use of this system is unproven and affords a higher level of risk. The balance of the technology selected for Alternative 3 is adapted from other airborne platforms, currently fielded, and present marginal risk in application to an ASW airship platform.

In summary, the unmanned ASW mission module, Alternative 3, offers the lightest weight, the lowest cost, lowest risk, best performance, and lowest manning requirements which make this alternative the recommended solution.

I. INTRODUCTION

A. BACKGROUND

The task of Anti-Submarine Warfare (ASW), largely the purview of the U.S. Navy submarine force during the Cold War and post Cold War eras, must move into the 21st century to remain effective against current and future threats. The Office of the Chief of Naval Operations established Task Force ASW in 2004 and chartered it to develop the Navy's ASW Concept of Operations for the 21st Century. Task Force ASW found:

> The ASW capabilities we possess today when confronting potential enemies are based largely on skills developed during Cold War. To sustain our operational advantage, the team must develop additional skills, implement them in an innovative manner, and rapidly leverage advanced technologies to swiftly defeat enemies wherever they may be found.[1]

1. Transformation and ASW

Seeking to meet this challenge, the Navy embarked on a mission to transform the way in which it conducted ASW. Several organizational and policy changes were made to take ASW into the 21st century. Commander, Third Fleet (C3F) and Commander, U.S. Fleet Forces Command (CUSFFC) were tasked to coordinate and focus ASW efforts. In October 2007, the Naval Mine and ASW Warfare Command was aligned to C3F under Commander, Pacific Fleet (CPF) to place the Navy's ASW strategic and tactical thinking under one umbrella.[2] ASW was a large part of the Sea Shield pillar of the Sea Power 21 Strategy and with C3F designated as the Sea Shield Operational Agent; C3F became responsible for all ASW efforts. Sea Shield is one of the pillars established by the Sea

[1] Task Force ASW [2004:p. 1]
[2] Waickwicz [2006]

Power 21 Policy Paper by then CNO, ADM Vern Clark.[3] This new alignment allows for increased advocacy and emphasis in the ASW mission area.

The Navy's long term transformational strategy depends on tactical and technological advances in the areas of:

- Enhanced signal processing
- Bistatic towed arrays
- Low frequency arrays
- Advanced deployable systems
- Advanced sonobouys
- Periscope detection systems
- Common maritime picture
- Open architecture torpedoes
- Torpedo countermeasures

2. The Navy's Task Force ASW Operational and Long-Term Objectives

These above technologies will enable the Navy to achieve the following two key operational level objectives as expressed in the ASW CONOPS for the 21st Century:

> "**Hold Enemy Forces at Risk:** The team will deny enemy submarines an offensive capability by maintaining the ability to destroy them, if and when required, at a time and place of our choosing.
>
> **Secure Friendly Maneuver Area:** The team will drive away or destroy enemy submarines, thereby protecting maritime operating areas. The team will protect US and coalition naval combatants, support ships, and merchant shipping from undersea attack within and enroute to vital operating areas."[4]

Sea Shield and Sea Basing play important parts in achieving these objectives. Whether it is holding enemy forces at risk through controlling choke points (Sea Shield)

[3] Clark [2002]
[4] Task Force ASW [2004:p.2]

or securing friendly maneuver areas through Sea Basing, both are integral parts of 21st century ASW.

The long term policy objectives of the U.S. Navy are also described by Task Force ASW. In order to continue to hold enemy forces at risk, the long-term ASW transformation includes use of:

- Distributed netted sensors
- Rapid attack the weapons
- Advanced data relays
- Integrated weapons systems[5]

The long term policy also lays out a force that possesses the following attributes:

- Persistence
- Pervasive awareness
- Speed and operational agility
- Technological agility[6]

The development of new technologies is encouraged to follow a prioritization of sensors over the weapons and networks over platforms as the battle is carried forward into the 21st century.

3. ASW Operational Principles

Task Force ASW lays out six operational principles and associated capabilities for future ASW system. This research directly addresses four of them:

> **“**Persistent Detection & Cueing. The networking of rapidly deployable and fixed surveillance systems will maximize enemy detections, tracking, and engagement opportunities.

> “Combined Arms Prosecution. Tracking and engagement of enemy submarines will be executed through coordinated and integrated Joint Force ASW operations, enhanced by common operational and tactical pictures that permit precise targeting and the weapons employment.

---

[5] Task Force ASW [2004: p.2]
[6] Task Force ASW [2004:p.3]

> "High Volume Search & Kill Rates. Agile technology development will maximize search and kill rates, resulting in greater numbers of enemy submarines destroyed per unit of time. These advancements will be achieved by the combined employment of large area search systems, highly accurate localization techniques, and standoff, precise attack systems.
>
> "Non-Traditional Methods. New technologies will yield enhanced operational agility by employing miniaturized sensors, the weapons, and command and control systems, as well as reconfigurable manned and unmanned vehicles. Such non-traditional methods will be employed from pre to post-hostility operations, generating effects that range from influencing threat behavior to destroying enemy forces."[7]

4. ASW Threats

The operating forces take all aforementioned policy guidance and turn it into operational and tactical doctrine. Scenarios from guarding and surveillance of choke points in the littorals to securing a sea base for carrier strike group operations are all considered. Through the use of maritime patrol aircraft, principally the P-3C, to the use of nuclear submarines and ASW equipped surface ships, the Navy conducts a variety of ASW operations to protect against the current threat.

The present ASW threat has shifted from the fast, deep-diving, blue water threat of the Russian Navy to the slow speed, quiet, and littoral submarine forces used around the world. The end of the Cold War, combined with the collapse of the Russian economy caused the once powerful Russian submarine force to atrophy. Many Russian nuclear submarines remain tied up at piers and continue to exist in conditions beyond repair. However the proliferation of diesel powered or Air Independent Propulsion submarines around the world continues. According to *Jane's Fighting Ships*, approximately 46-48 countries operate submarines; of these, 39 boast what are

[7] Task Force ASW [2004:p.5]

considered “quiet” submarines. Fortunately, less than a handful pose significant threat to the security of the United States.[8]

Today, China operates one of the largest submarine forces and has a significant surface force as well.

> “The PLA Navy has 70 principal combatants (25 destroyers and 45 frigates), 55 submarines (50 diesel and 5 nuclear), some 50 medium and heavy amphibious lift ships (an increase of over 14% since 2005), and about 45 coastal missile patrol craft.”[9]

By comparison, the U.S. Navy operates a nuclear submarine force of 52 fast attack submarines (SSN),[10] 4 guided missile submarines (SSGN),[11] and 14 ballistic missile submarines (SSBN).[12] Furthermore, China has an aggressive training program in an attempt to gain proficiency in submarine operations and tactics. The People’s Liberation Army Navy (PLAN) under took significant training reforms in 2002 which included:

> “The old concept of single submarines departing early in the morning and returning late on the same day was replaced with the concept of multiple submarines conducting navigation training together over multiple days throughout the day and night. The old concept of single submarines conducting independent training was replaced with multiple submarines attacking as a task force. The PLAN replaced the old basic training method of simple and redundant training with mission-oriented training subjects. The old method of training on single submarine tactics per sortie

8 Janes [2001-2002]
9 Office of Naval Intelligence [2007:p.122]
10 SSN Fact Sheet [2007]
11 SSGN Fact Sheet [2007]
12 SSBN Fact Sheet [2007]

was replaced with training on several combined-arms tactics simultaneously in a combined-arms environment."[13]

The PLAN has begun extending both the range for some of its submarines and increasing the duration of some training events as evidenced by the events in October 2006 when a Song-class, diesel-electric submarine surfaced within 5 NM of the aircraft carrier, USS Kitty Hawk, in the South China Sea. This single event caused the U.S. Navy to refocus its efforts on anti-submarine warfare. Task Force ASW stated, "The objective of 21st century ASW operations is clear: to secure the battlespace from undersea threats by swiftly destroying enemy submarines."[14] However, there are still advocates for "non-lethal" ASW methods, which for the most part are beyond the classification of this paper and therefore not discussed here.

B. PURPOSE

The focus of the Keyport Cohort of the Naval Postgraduate School (NPS) Masters of Science in Systems Engineering (MSSE) project is to examine the use of hybrid aircraft technology to see if it has the potential to revolutionize and transform the way the U.S. Navy conducts ASW by developing recommendations for an ASW module to be carried by a hybrid aircraft.

At the request of Combatant Commanders (COCOMs), plans are being made to develop a 50-ton proof-of-concept demonstrator of a hybrid aircraft called the Hybrid Airship Multi-Role (HAMR), conceptually shown in Figure 1.

[13] Office of Naval Intelligence [2007:p.37]
[14] Task Force ASW [2004:p.5]

Figure 1. Lockheed-Martin P-791 Demonstrator [2007].

Hybrid aircraft provide a persistent, survivable, versatile capability that cannot be found in any other single asset. They can take off and land unassisted on land or sea, carry large payloads (potentially up to 1,000 tons), stay in the air for days, travel at speeds up to 100 knots, and take a remarkable amount of damage before losing lift. This concept and the alternatives that are offered directly address the operational principles and associated capabilities for future ASW system as stated by Task Force ASW. With the capability to remain on station for days at a time, a hybrid aircraft can provide a platform for persistent ASW detection and cueing. Alternatives are possible that bring to bear the forces of surface, air, and sub-surface ASW platforms in combined arms prosecution of enemy submarine forces. The extraordinary lift capability of the hybrid airship allows it to carry many sensors and retain the ability to move over large volumes of ocean which will provide high volume search, and when appropriately armed, corresponding kill rates.

The use of hybrid aircraft technology can be considered as non-traditional methods and technologies. New technologies yield enhanced operational agility by employing miniaturized sensors, weapons, and command and control systems, as well as reconfigurable manned and unmanned vehicles. Such non-traditional methods will be employed from pre- to post-hostility operations, generating effects that range from influencing threat behavior to destroying enemy forces. The use of an ASW module on a hybrid aircraft can be considered as a force multiplier.

During a recent National Defense Industrial Association (NDIA) briefing at the Joint Undersea Warfare Technology Conference, a representative for Program Executive Office – Integrated Weapons Systems (PEO-IWS 5) stated the single largest challenge for them in ASW is to develop or acquire an ASW system that is "tailorable" and scalable across many platforms.[15] The alternatives presented in this paper can be tailored and are in line with those currently in use as well as planned future technologies. This project is easily adapted to use the future open architecture design concept for sensors and the weapons.

At the same conference, the need for a platform to perform mobile, ASW escort missions for slow moving ships was discussed. Some consider this the toughest mission for the surface warfare arm of the Navy. The hybrid aircraft could address this mission.

The purpose of the demonstrator is to display the capabilities of hybrid aircraft technologies and prove technical readiness for the development of the 1,000-ton Hybrid Ultra-Large Aircraft (HULA) and ASW module. This also will pave the way for other mission modules unlike the concept of the Littoral Combat Ship. The future mission modules could fulfill a variety of missions ranging from ASW, Search and Rescue (SAR), Command and Control (C&C), ISR (Intelligence, Surveillance, and Reconnaissance) or ISTAR (Intelligence, Surveillance, Target Acquisition, and Reconnaissance), or others. These modular payloads could fulfill a variety of missions as discussed above.

C. SCOPE

The Naval Undersea Warfare Center (NUWC) Division Keyport team examined alternative designs for an ASW module for use on the HAMR demonstrator. The team explored different combinations of existing ASW sensors and weapons systems for the ASW mission module and evaluated their different technical, logistical, and fiscal considerations using systems engineering (SE) principles.

The project focused on developing a design for an ASW module with capability that optimizes overall primary mission effectiveness and emphasizes the unique potential

[15] Benedict, PEO-IWS 5 [2008]

of the HAMR platform. To appropriately bind the scope of this academic effort, the team imposed some limitations. Only existing systems or those that could be realistically fielded in the next five years would be considered for use in the ASW module. This would facilitate rapid prototyping as recommended by the stakeholders' initial requirements. Efforts for this project were concentrated on the ASW capability module rather than the HAMR airframe. Assumptions about the airframe and its capacities are outlined in the assumption section of this paper if not specifically described by stakeholders and subject matter experts (SMEs).

The team developed up to three operational scenarios that were obtained from a framework of specific, realistic ASW scenarios which are rooted in the following concepts. Given that the U.S. Navy has air superiority and the knowledge of regional/local weather conditions throughout deployment of the HAMR, the following scenarios could apply:

> *Standalone HAMR Area ASW*—In conjunction with a Carrier Strike Group (CSG), which is tasked to defend the HAMR from air or surface threats, the HAMR conducts independent searches and conducts/coordinates ASW attacks (by other ASW platforms including other HAMRs) in order to clear an area or prevent intrusion by a submarine.

> *Coordinated HAMR Area ASW*—Deployed with other ASW platforms, i.e. ships and subs, HAMR provides either in-depth (e.g. outer) ASW defense or sector (e.g. flank protection) defense for either a CSG or Expeditionary Strike Group (ESG).

> *Littoral Patrol*—Deployed in stand alone mode, protected by either sea assets or shore based assets, HAMR conducts just searches or searches and attacks on submarines. Other ASW platforms (i.e. rotary and fixed winged aircraft, submarines and ships) can launch attacks if HAMR is only in a search mode. HAMR monitors shipping from in or out of the port, identifies

and tracks suspect platforms, provides communications and sensor data relay for shore base units, and deploys and monitors sensors. [16]

The scope of the project will look at how the HAMR can be used in comparison with the current methods employed by Maritime Patrol Aircraft (MPA), principally the P-3. The team also considered the airship as a stand alone entity and something the team would not be designing. The HAMR module would be carried by the airship; in similar fashion it would carry other mission modules.

The persistent design of the airship can lend itself well to other missions. Mine warfare is one possible future mission. As the airship can move slowly and search large areas, it can be used to defeat and clear enemy mines. Other missions are possibilities as well such as search and rescue (SAR), intelligence missions, electronic warfare (EW), and homeland security. The efforts of this team will concentrate only on the ASW module.

D. METHODOLOGY / APPROACH

The overall methodology that guided the HAMR team's approach was the system engineering design process illustrated in Figure 2. The HAMR team performed the steps of a systems engineering design process (SEDP), which is described in more detail in the following paragraphs. The problem definition phase of the SEDP phase resulted in a descriptive scenario which was refined via the needs analysis and value system design phase. The needs analysis phase resulted in an effective need. The revised need was used as an input into the design & analysis phase. The HAMR team progressed through the alternatives generation and modeling and analysis phases. The results of the modeling and analysis phase yielded recommendations for the decision making phase. The alternatives were scored based on quantitative modeling outputs and qualitative criteria. Several alternatives were vetted to determine the best valued solution.

[16] Rarig [2007]

1. Problem Definition Phase

The problem definition is the first and most important phase of the SEDP. It allowed the team to understand and define the problem so that the design fit the solution. It consists of two steps, needs analysis and value system design.

The problem was originally defined as fielding an ASW prototype module for a 50 lifting ton, lighter-than-air HAMR demonstrator platform. The module is to be removable to allow the host platform to be reconfigured for various mission options.

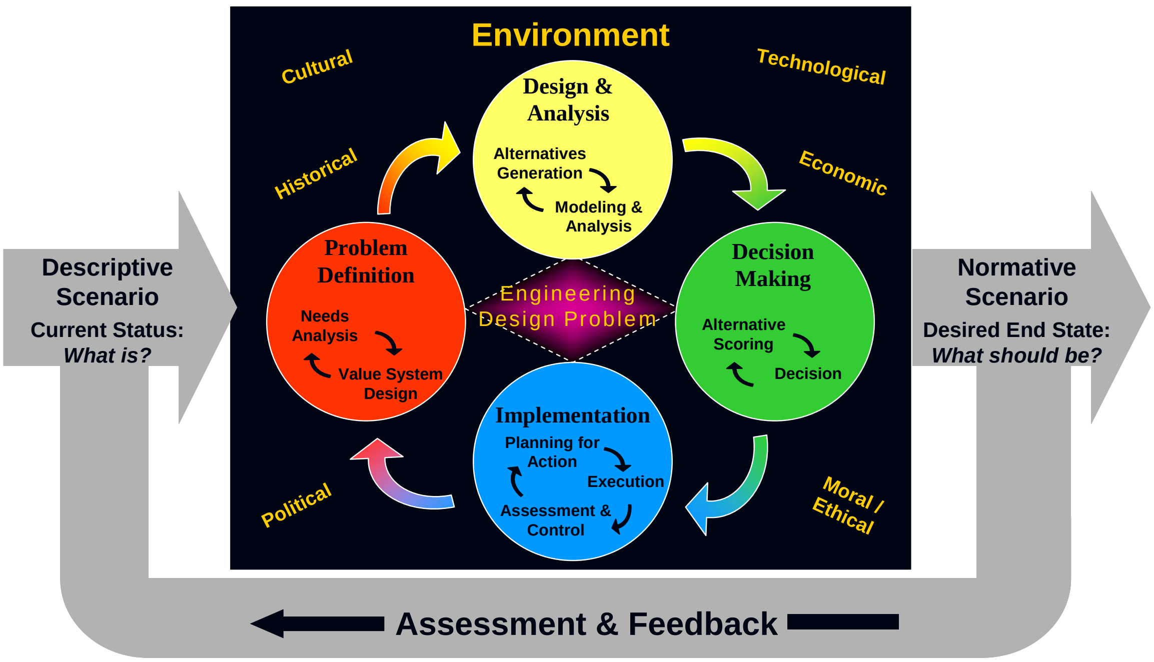


Figure 2. Systems Engineering Design Process. NPS SI4007 [2006].

a) Needs Analysis

The needs analysis process translates the primitive need into a more refined definition of objectives intended to meet the stakeholders' needs. The primitive need was defined as the need for an ASW mission module for the HAMR platform. The team conducted stakeholder analysis to generate a list of needs and wants from the relevant stakeholders. Information was collected by conducting interviews and through the distribution of questionnaires. Follow-on discussions were conducted when necessary to obtain additional details and clarifications. Initial efforts will be to expand

the design space and generate a wide variety of alternatives without regard to constraints. Many ASW systems were considered for integration into the HAMR modules using many SEDP techniques such as brainstorming, functional flow charts, and morphological boxes.

The team determined the suitability and feasibility of the capabilities for incorporation into the HAMR. The principle objective is to generate alternative capabilities in the areas of sensors, processors, and the weapons. An input-output model of the HAMR was generated to properly ‘scope and bound’ the system. The needs analysis phase resulted in an effective need.

The team conducted research to identify current ASW threats or gaps in existing systems, which influenced the development of the HAMR’s concept of operations and mission requirements. Other sources of input for the needs analysis phase consisted of SME interviews, printed material, and media. Operational scenarios were proposed to further understand the environmental requirements, system constraints, and support infrastructure.

b) Value System Design

The value system provides a top-down view of what is to be accomplished, the relative value of those accomplishments, and by what means they will be measured. The effective need will be the foundation for the value system.

c) Objectives Hierarchy

The objectives hierarchy is divided into systems, functions, and their associated metrics. Building further on the foundation laid by the needs analysis, the team developed a value structure consisting of functions, sub-functions, objectives, sub-objectives, and evaluation MOEs. This structure, also presented as a hierarchy, is the foundational tool of the Multi-Attribute Utility Theory (MAUT) used to evaluate alternative solutions as described in section IV.

d) Performance

The functions of performance include the ASW capabilities and manning. ASW tasking includes objectives such as tracking, engaging, detecting, localizing, classifying, as well as communicating proximal targets. The tracking objective of the ASW function was measured by the percent of time it takes for the target to come within range. ASW performance measures of effectiveness (MOEs) used are detection and tracking capability and mission duration. The measurement for integration (another function of performance) can be simply evaluated on a pass/fail basis. MOEs are largely based on quantitative analysis. Objectives were measured based on the operational characteristics of the proposed alternatives. The objectives are measured with corresponding MOEs.

e) Life Cycle Cost

The categories used to determine the life cycle cost (LCC) are the procurement, integration, logistics, operational, maintenance, and disposal costs. Procurement and production, operation and maintenance, demilitarization, and disposal cost for retiring the ASW modules are included within the LCC analysis.

f) Weighting

Using all of the research and inputs provided by the needs analysis, weights are assigned to each function, objective, and sub-objective in the value structure. The weights can be represented in two different but related ways: local and global. Local weights are presented with each of the categories and subcategories requiring values that sum to 1. In other words, when summed, all of the weights for all of the functions, all objective weights under a single function, and all of the sub-objective (if applicable) weights of a single objective total 1. Global weights are the product of the local weights of an item and all of its parents—each category (function, objective, and sub-objective) in the value structure. The sum of the global weights for all items is also 1. These weights establish the relative importance of each item in the value system and are used in the multi-attribute decision analysis to assign the proper weight to the outcome of a certain function or objective as it relates to the overall system effectiveness.

2. Design & Analysis Phase

a) Alternatives Generation

Proposed alternatives were varied to provide the decision maker with contrasting alternatives. Several design analysis iterations yielded various systems alternatives designed to perform the functions required by the HAMR CONOPS. The alternatives were composed of existing ASW systems to not only limit risk but to take advantage of the Navy's vast resources. The functional requirements implied by the CONOPS were mapped to physical systems through comprehensive research of current ASW functions and systems. Physical alternatives were vetted based on many factors such as integration feasibility, ASW system performance, and operational effectiveness.

b) Modeling and Analysis

The proposed alternatives were modeled in different ASW scenarios to determine their operational effectiveness. The alternatives and systems that were deemed feasible were given a cost benefit analysis to determine how much capability can be provided at what associated cost. The cost of the system is looked at from multiple perspectives. Unit price, estimated integration costs, and manpower costs were all factors in the total system cost. The key physical specifications are incorporated into some models to perform a comparative analysis of a particular system. The key performance specifications of interest are the volumes a system occupies, the weight, and power consumption of each system. These were included in the cost models for comparative reasons. A cost effective system may not be suitable because it occupies too much space or consumes an excessive amount of power. The approach taken was not to duplicate the alternatives generation phase but instead to examine the key outputs of the alternatives generation phase. The key outputs space, weight, and power consumption are thus the only physical performance specs that are incorporated into cost comparison models. SMEs provided unit prices, physical characteristics, and capability estimates. Unknown variables such as integration costs were given best effort analyses to determine reasonable cost ranges. The physical characteristics and system capabilities were weighed against their associated costs. System cost estimates were categorized by

capability in order to determine what area the focus of monetary investment will be made for a particular configuration.

The modeling phase provided performance baselines for various configurations. Performance simulations were created to compare each alternative system under consideration from an operational standpoint. Physical configurations exhibiting the most effectiveness for a given operational scenario were analyzed in more detail. This modeling approach insured more fitting configurations, each of which customized for its specific test scenario. The resulting data from this detailed analysis was then reincorporated into the team's cyclic design analysis process. The alternatives were compared using a cost benefit analysis. Logistics requirements were considered among many other factors that ultimately determined alternative feasibility. The resulting design and analysis iterations produced best fit system proposals.

Spreadsheet tools were used to capture system data and mathematically analyzed and graphically illustrate the relationships and relative costs between systems. Absolute cost was used as one factor for future feasibility screening. Data collection required a comprehensive and tedious research effort spanning various Navy facilities as well as non-military organizations. Any information that was available, pertinent, and unclassified was collected for possible model inputs. Actual costs, SME input, confirmed specifications, as well as best effort estimates all provided input to the HAMR ASW mission module cost models.

3. Decision Making Phase

Each alternative was thoroughly analyzed. Every alternative is made up of multiple subsystems. To generate a cost estimate for a single alternative, the cumulative costs of the subsystems were accounted for as accurately as possible. The cumulative weights and power consumptions were also critical inputs that were provided to the decision makers. Weighting techniques were used to score the alternatives.

4. Implementation Phase

A recommendation for a practical implementation was made after scoring the alternatives. The ASW mission module project is to provide the stakeholders with a

recommendation on a prospective prototype mission package. Our recommendations will be provided to the sponsor for assessment and subsequent implementation.

II. PROBLEM DEFINITION

A. INITIAL PROBLEM STATEMENT

The problem which was initially provided by the stakeholders (U.S. European Command (EUCOM), Space and Naval Warfare (SPAWAR), U.S. Air Force, NUWC Division Keyport, Naval Sea Systems Command (NAVSEA) 05, Naval Air (NAVAIR) Systems, Lockheed Martin)[17] includes the stakeholders' interest in a constant airborne presence, an airship with greater lift capabilities, and in tactical modules for hybrid aircraft demonstrator. The problem has been defined as fielding an ASW prototype or concept module for a 50-lifting ton, lighter-than-air demonstrator platform. The module is to be removable to allow the host platform to be reconfigurable for various mission options. In addition, power is to be provided by the host platform.

B. NEEDS ANALYSIS

1. Stakeholder Analysis

The charter of the Chief of Naval Operations Task Force ASW and the stakeholders' needs statement provided the foundation to the concept of the HAMR performing ASW roles. This was also the starting point for the systems engineering process. Numerous stakeholders from the various commands vying for a common goal in the advancement of ASW in the 21st century afforded a wealth of knowledge to pool from in approaching the surveys for our stakeholders. The purpose of the stakeholder survey is to focus the direction of the effort in the problem definition, design analysis, and decision making phases of the systems engineering process. The system engineering process is an iterative process. Feedback from the stakeholder surveys help shape the needs analysis and the value systems design. The stakeholder analysis and research comprised of the initial surveys, interviews, and research on ASW platforms, combat systems, equipment, surface & subsurface sensors, tactics, environment, and doctrine.

[17] Allocca [2007]

A complete list of stakeholder questions is located in Appendix A. Sample survey questions include:

- External considerations
- How/who will the airship operate with?
- Is the HAMR part of our engineering effort?
- System considerations
- Will the team be developing/considering new or immature technologies?
- At what technology readiness level (TRL) should ASW systems be considered for this project?
- What secondary missions could this possibly perform?
- ISR
- Mine warfare (MW)
- Electronic warfare (EW)
- Missile defense
- Small boat defense
- Torpedo defense
- Should the team consider functions outside of ASW in our objectives?

Stakeholder survey research was done by a series of e-mails, telephone calls, and interviews of SMEs. The team was able to gather information on what questions to ask the stakeholders for this project. Further research enabled the team to create a stakeholder questionnaire which helped the team work through the problem definition phase.

Stakeholder analysis was primarily used to discuss the stakeholders' needs. From the use of the stakeholder survey, the team was able to evaluate common goals, create an initial needs statement, and begin the systems engineering process.

The feedback from stakeholders David Allocca, Donald Statter, Tim Busch, and Scott Rarig provided the problem definition and needs analysis.[18] The feedback also generates other aspects of the SEDP.

Stakeholders have unique interests which may not always align with one another. This is to be expected when projects span commands and sponsors. It was the team's task to merge interests in an unbiased way to successfully address the needs of the stakeholders.

For example, one stakeholder felt critical capabilities should be:

[18] Allocca[2007]

- 24/7 coverage
- Keep subs out of torpedo attack zone (Primary)
- Keep subs out of cruise missile attack zone or provide superb cruise missile defense (secondary due to the existence of Aegis escorts)
- Provide network relay
- Deep magazines for fighting a high tempo battle[19]

In contrast, another stakeholder felt that critical capabilities should be that "…all detected objects should be plotted as icons on a moving map display system such as FalconView. Detected object data will be transmitted to remote users in real-time by use of data links and IP networks."[20]

2. Current ASW Capabilities and Operations

a) Fast Attack Submarine

The SSN, or fast attack submarine, is often considered the primary platform to conduct ASW for the Navy. However, with shrinking budgets and drastic reductions in numbers of submarines and ships combined with the limited flight hours of the P-3 Orion, the Navy must explore new and innovative ways to conduct the ASW mission.

While acknowledged as a first choice to combat enemy submarines, the drastic reduction in the number of submarines in the force makes it impractical to place such high dependency on them. Although they can easily operate in the littoral environment as well as open ocean, the paucity of their numbers combined with other high priority missions may limit the use of the SSN in some theaters.

b) Surface Ships

Surface ships, in combination with embarked helicopters, are another layer of the defense of the carrier. Advances in technology enabled the design of better sonars and use of towed arrays for the surface ships. However, these ships are still needed in relatively close proximity to the carrier. In addition to the ASW mission, the CGs, DDGs, and FFGs still play an important role in anti-air warfare and missile defense for

[19] Allocca [2007]
[20] Statter [2007]

the carrier. This important mission may also prevent proper search techniques or positioning for best submarine search.[21]

c) P-3 Orion

"The P-3 Orion is a peerless airborne hunter. Its reputation as the ultimate submarine finder was earned through more than 45 years of service, from the Cuban Missile Crisis to round-the-clock, low-profile patrols throughout the Cold War. The P-3 remains a relied-upon asset today and has proven to be remarkably well adapted for maritime patrol in the post-Cold War world. In fact, no other aircraft is better suited."[22]

As seen from the quote above from leadership at Lockheed Martin, the P-3 has been in service for over 4 decades. This platform is aging and the claim that no other aircraft "is better suited" for the maritime patrol mission is debatable. The recommendations presented in this paper will provide alternatives to the P-3 for conducting the airborne ASW mission.

As the Navy heads toward the use of distributed, networked sensor fields, the recommendations presented will be able to play an important part in the mission. Whether by placing sensor fields or sonobuoys, tracking or relaying data, or conducting attacks, the HAMR is well positioned to meet the ASW mission.

3. Concept of Operations

A concept of operations reflects the mission as well as environmental requirements. It will also show how the system is generally intended to be used. Within the concept of operations, different scenarios will be considered.

The HAMR and ASW module will be used in various environments in which our forces maintain control. Operating at altitudes up to 20,000 feet, it is an all weather platform designated to perform the ASW mission. It will operate day or night in all sea states and in 50kt wind conditions. The airframe has a range of 2,200 NM and can operate independently for up to ten days at a time. HAMR is to be used in areas where the U.S. possesses air superiority to prevent attack from enemy forces.

[21] Task Force ASW [2004]

[22] Lockheed Martin [2008]

The HAMR ASW module is considered in two operational scenarios: stand alone patrol and maintaining a safe operating area for a CSG. The module provides such support by effectively executing its ASW functions as depicted in Figure 3.

Figure 3. HAMR Tactical ASW Concept of Operations.

a) Stand Alone Patrol

The HAMR, equipped with the ASW module, may be used as a single patrol asset (Figure 4) against open water or confined threat areas. This would be accomplished by having the HAMR module strategically deploy and monitor sonar sensors. The module would actively process the data returned by the sensors allowing the HAMR to aggressively pursue, track, and engage (or call other assets to engage) all unidentified submarine contacts. Other ASW assets may be alerted with the modules ability to communicate with various platforms if the situation calls for alternate types of engagement or means to alter the threats' course of action.

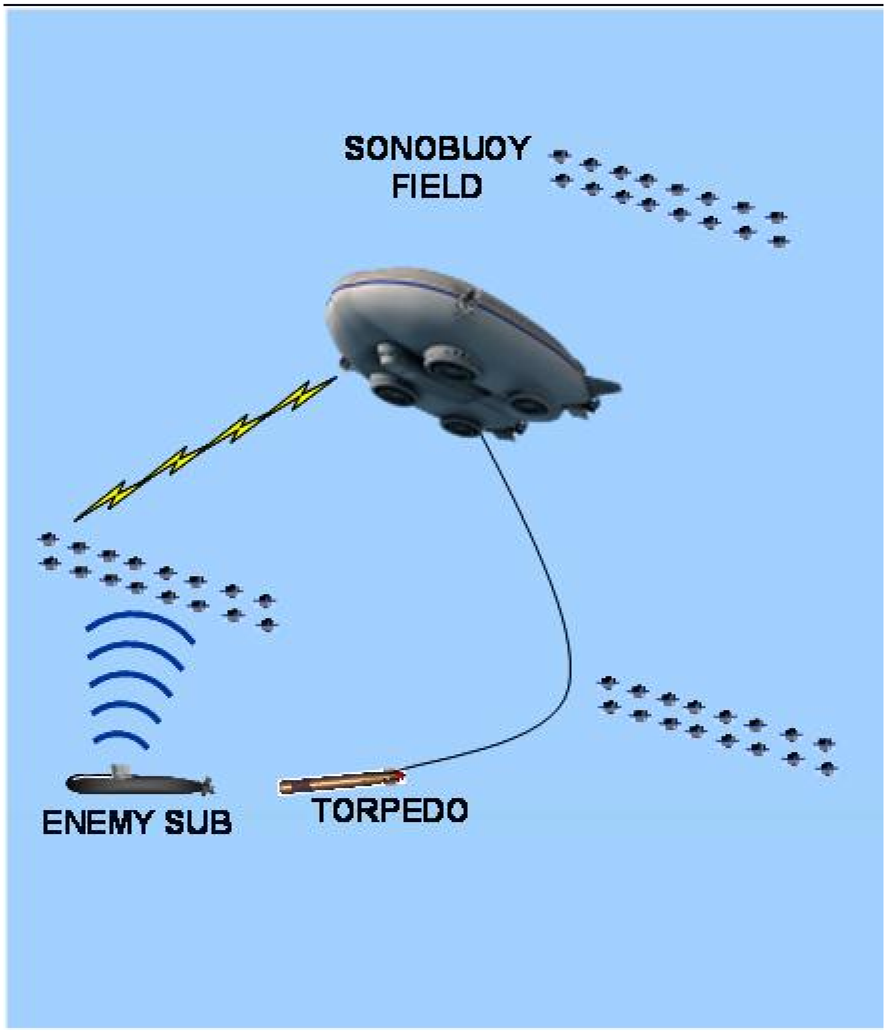


Figure 4. Stand Alone Patrol Concept of Operations.

b) Safe Operating Area

The HAMR ASW module may also be used to maintain a safe operating area (SOA) for a CSG or ESG (Figure 5). The ASW module would act as a communications hub for all other assets allowing strategic planning using real-time data passed between the module and additional assets. The module would be capable of deploying and monitoring sensors within a certain radius, sharing any detections and tracks as a result of the data returned by the sensors. This application would ensure no enemy submarines could intercept forces within the SOA. Upon detection of a threat the module would be equipped to engage or have an alternate asset execute the engagement.

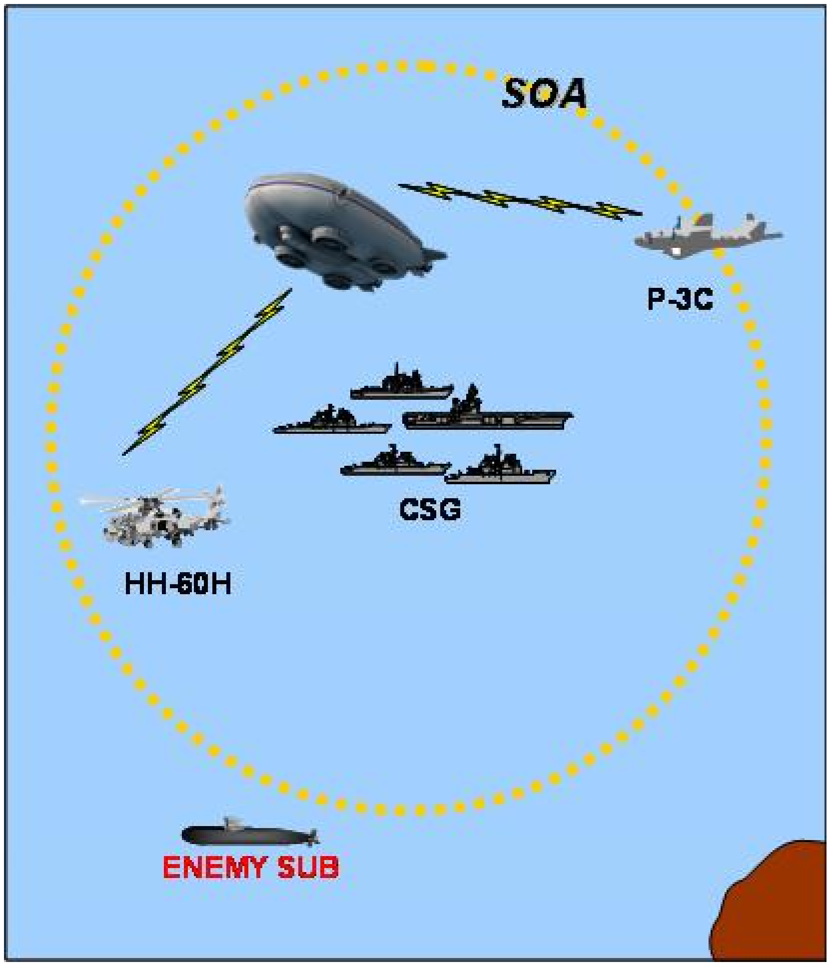


Figure 5. Safe Operating Area Concept of Operations.

4. Mission Requirements

The mission requirements are defined and refined throughout the SEDP. Mission requirements are obtained through stakeholder analysis and research, tying both the current and future needs together into a deliverable to meet the effective need.

The team must base design decisions in fulfilling this gap without compromising the effectiveness of the deep water capabilities. Combat in the littorals pose unique and interesting challenges that the ASW module can help overcome if the correct variations of alternatives are put together. Challenges that are faced in the littoral are:

- Acoustic propagation in shallow water
- Sea floor characteristics

- Proximity to land
- Limited ship maneuvers due to shallow waters
- Limited submarine maneuvers due to shallow waters
- Sensor degradation in shallow waters
- Use of sonar and towed arrays are limited
- Munitions' depth requirements

These are just a few examples of the challenges faced when architecting a system that is both effective in the littorals as well as the deep sea. The ASW module can be designed to fulfill stand alone missions or to act as a centralized unit tying the remaining ships in the battle group together. This will be accomplished by designing a platform that is capable of communicating with the various other platforms currently being used in the fleet for ASW. By providing this centralized service and communication capabilities, the HAMR ASW module may provide advanced battle space awareness, tracking, and engagement capabilities both in the shallow and deep seas.

The ASW module must also be designed in such a manner that it does not require unique support accommodations. It may very well be possible to utilize current and near future technologies incorporated into one package, the ASW module, to fulfill missions that would otherwise take multiple platforms to accomplish. Alternative analysis and modeling will be conducted to help define the recommended system.

5. Threats

The Navy faces greater challenges with the advancement of propulsion systems, sensors, and armor being integrated into smaller, more versatile submarines. Focus has shifted toward influencing the outcome of war closer to the shore where these submarines may alter the battle space. It has become increasingly important to control the sea from the deep to shallow waters. The inability to approach coastal waters may hinder the Navy's effectiveness against threats on- and offshore. In addition, diesel submarines present a significant threat because they are virtually undetectable while operating on battery power.[23] Combine this with the complications of acoustic signature detection in shallow water and the summary equates to the challenges of ASW in the littorals.

[23] Kakesako [2008]

Discussions with stakeholders indicate that the littoral threat is very real and increasing.[24] With the advancement of mines as well as submarines, the Navy must take action to maintain a formidable position against the shallow water threats.

6. Disposal and Demilitarization

The purpose of the disposal effort is to consider the demilitarization and disposal of HAMR ASW equipment at the end of its useful life. The HAMR program must ensure that there is sufficient information to enable disposal to be carried out in a way that is in accordance with all legal and regulatory requirements relating to safety, the environment, and security.

The Systems Safety Officer (SSO) should ensure that hazards associated with disposal and demilitarization of the system are identified and resolved early in the life of the system through the application of system safety management and engineering principles. While some alternatives may contain small amounts of hazardous materials (HAZMAT), they will not expose users under normal conditions. All HAZMAT materials should be identified before the disposal and demilitarization process and will be taken into consideration for the appropriate action.

The HAMR program should maximize environmental protection by specifying any alternative that utilizes materials which do not adversely affect the environment. Recycling and reprocessing considerations will be considered for all alternatives to maximize the best option during disposal and demilitarization.

All systems that are considered a security risk will take appropriate action upon disposal and demilitarization. The primary concern is to prevent the inadvertent disclosure of sensitive information stored on computer hard drives or within the related equipment.

Detailed demilitarization and disposal plans will be prepared as the system approaches the end of its useful life. If major subsystems or mission systems become obsolete, detailed plans for their demilitarization and disposal will be prepared at the appropriate time.

[24] Heady [2008]

7. System Constraints

The ASW module is bounded by the limitations of the demonstrator version of the HAMR. Physical attributes such as size and weight and the technology maturity are also limitations. Based on the information provided by the stakeholders, the HAMR is capable of lifting approximately 50 tons.[25] Throughout the alternatives analysis and selection process, the total weight of the subsystem combinations will be considered to ensure that the team complies with the weight constraint of the HAMR.

Given that the HAMR is not intended to have a powerful thrust from its engines, the overall drag the module adds to the HAMR is taken into consideration. The module will be designed to fulfill the ASW mission need along with as little added drag as possible by selectively going over the alternative combinations that can deliver a balanced solution. Solutions that require the module to have external extremities underneath it will inflict the most added drag to the system. However, the alternative will not be ruled out as it may provide the essentials for fulfilling the mission needs.

In addition to the physical constraints, timing is a critical factor in the development of the ASW module. The prototype is scheduled to be developed within the next five years. The technology maturity of the alternative selections is crucial in meeting the time constraint of five years. To ensure technology maturity, only existing technologies and technologies that were "fieldable" within five years were considered. TRLs are measured on a scale of one to nine, one – two range being "basic technology research," increasing to "system test, launch and operation" at level nine. For this project, it was determined that only technologies at a TRL level of five or greater (five being "technology demonstration") would be considered.

8. Assumptions

Given that the HAMR is a prototype, there are several unknown system constraints. For instance, we are currently designing alternatives with the assumption that the HAMR will provide all the electrical power required by the ASW module. It is also assumed that the HAMR will follow conventional Navy power distribution practices.

[25]Meyers [2007]

The mechanical configuration and mating scheme, ASW module to HAMR, will be based on the premise that standard mechanical interlocking systems and seals will be used. The same can be said for the mechanical electrical connections. However, there is more focus on the overall performance analysis of the combination of subsystems that will best fulfill the effective need.

Assumptions are also made, but confined to, what has been researched and discussed among the stakeholders on the scenarios that would yield the best results among the alternatives. Utilizing the information obtained through the needs analysis, requirements, and scenarios, the project's scope may be limited to the following assumptions on what the HAMR and ASW module will be able to provide:

- Air Superiority – HAMR platform will not have to defend against anti-aircraft threats.
- Performance – The HAMR will perform as stated in "White Paper for Tactical Support Platform for Overland and Maritime Missions,"[26] but assume the following:
  - A towed array may be used effectively from airship
  - Dimensions (82x12x10) of the container used for the ASW module[27]
  - HAMR will work in all weather environments[28]
  - Max ceiling (unloaded/no cargo) 20,000 ft.[29]
  - Max speed 100 knots[30]
  - Cruise speed 75 knots[31]
  - Max Cargo 100,000 lbs.[32]
  - Fuel burn rate (fully loaded) roughly ~ 25 lbs/mi[33]
  - Hotel services are addressed by the airship not by the ASW module

9. Support Infrastructure

Support infrastructure encompasses the concept of providing a level of support capability and maintenance for piece parts, software, hardware, and components that are integrated into the prime mission-related elements of the system. This support is

[26]Allocca [2007]
[27]Myers [2007]
[28] Ibid [2008]
[29] Ibid [2008]
[30] Ibid [2008]
[31] Ibid [2008]
[32] Meyers [2007]
[33] Meyers [2007]

incorporated throughout the entire lifecycle including response to the maintenance and support infrastructure requirements. The support infrastructure is developed during the conceptual design phase, evolving from the definition of the system operational requirements and comprises of transportation and handling equipment, test equipment, the supply support capability, maintenance facilities, and other applicable elements of logistic support all addressed in the designed characteristics.[34]

10. Functional Analysis

Functional analysis is an iterative process of generating system requirements and transforming them into increasingly detailed design criteria. This process identifies the functions necessary for the system will be required to perform in order to accomplish the ASW mission.

a) Research

In order to facilitate the analysis and ensure accuracy and completeness, the team used three primary sources to obtain information, stakeholder analysis, existing platform functional analysis, and existing Navy policy and procedures.

As described in section II.B.1 the stakeholder analysis provided valuable insight into the expected functions of a HAMR ASW module. A summary of stakeholder feedback is given in Appendix A. While a great deal of useful information was gathered from stakeholders it was immediately clear that many of the functions that stakeholders envisioned the module performing did not fall within the ASW mission area. Some effort was needed to properly scope the system while at the same time considering every possible function.

To gain an understanding of current ASW assets and their functions, the team performed a functional decomposition on four ASW platforms. The four platforms, a P-3 maritime patrol aircraft, an H-60 helicopter, an AEGIS surface vessel, and a submarine were analyzed, and their ASW missions represented in a functional flow diagram. In order to make the best use of the resources available each IPT (see Appendix

[34] Blanchard [2005:p.71]

B for IPT structure) was responsible for performing the analysis and research for one platform.

b) Affinity Diagramming

Once the team was comfortable with the research that had been accomplished a series of meetings were held to establish the essential functions of the system. The affinity diagramming process, as described by Professor Gene Paulo[35] in his lecture notes and on the American Society of Quality (ASQ) website,[36] was used to organize and direct the affinity diagramming effort. The team first collected all of the information that had been gathered during research and listed all functions and sub-functions that were identified. After all team members were satisfied that all possible functions had been represented the functions where organized into functional categories. These functional areas include the following:

- Detect submarines
- Classify submarines
- Engage submarines
- Track submarines
- Localize submarines
- Communicate
- Air defense
- Mine warfare

This list includes many functions that stakeholders expressed an interest in incorporating into the system as well as functions that could be considered as secondary functions in the main ASW mission. All functions were evaluated against the primary ASW mission with respect to the project scope and the value added by the function to that mission. As a result of this evaluation and discussion among the project team, stakeholders, and advisors many functions where eliminated and the following functions were determined to be fundamental to the mission:

Detect: The ability of the proposed system to search a specified area and detect the presence of enemy submarines in that area.

[35] Paulo [2006]
[36] "The Quality Toolbox" [2008]

Classify: The ability of the proposed system to identify detected submarines correctly.

Engage: The ability of the proposed system to terminate or alter the mission of known enemy submarines.

Track: The ability of the system to effectively maintain an accurate track on an enemy target.

Localize: The ability of the system to reduce the area of uncertainty of the location of the submarine sufficiently to engage the submarine.

Communicate: the ability of the system to effectively and reliably communicate with own force and allies.

Detection can be broken down into sub-functions including queuing, search plan (surface & subsurface), environmental planning, surveillance, and loitering. Sub-functions of communications include battle group connectivity, airframe and pilot communications, over the horizon relay, receiving intelligence, and data transmission. The engage function includes the sub-functions to destroy, disable, deceive, or deter. Tracking encompasses the sub-functions of data collection, maintain contact, observe, and report. Classify includes data processing, data comparison, determination of contact (friend or foe), and the determination of threat level. Localizing a threat has sub-functions of positioning of friend or foe and determining a fire solution.

c) Functional Flow and Functional Hierarchy

Using the functions and sub-functions identified in the previous section, functional flow and functional hierarchy diagrams were assembled.

The functional flow diagram, shown in Figure 6, represents the flow of data or responsibility from one function or sub-function to another. The functional flow diagram is helpful in visualizing and establishing how, were, and when each function fits in the ASW mission. Like all flow diagrams, the functional flow diagram is intended to illustrate how a process, or multiple processes, is performed. The illustration in Figure 6 includes flow paths represented as lines with arrows, decision points represented as circles containing the letters 'Y' and 'N', logical operators represented by circles

containing the words ‘AND’ or ‘OR’, and activities or functions represented by rectangular boxes.[37] The primary functions are displayed as large green colored rectangles and the sub-functions are displayed as smaller, grey-blue colored rectangles.

The purpose of the functional hierarchy, shown in Figure 7, was to provide a logical representation of how functions and sub-functions were related to each other. The functional hierarchy also provides a natural basis for the inclusion of objectives and the establishment of a value system which will be discussed later.

[37] Sage [2000: P.131]

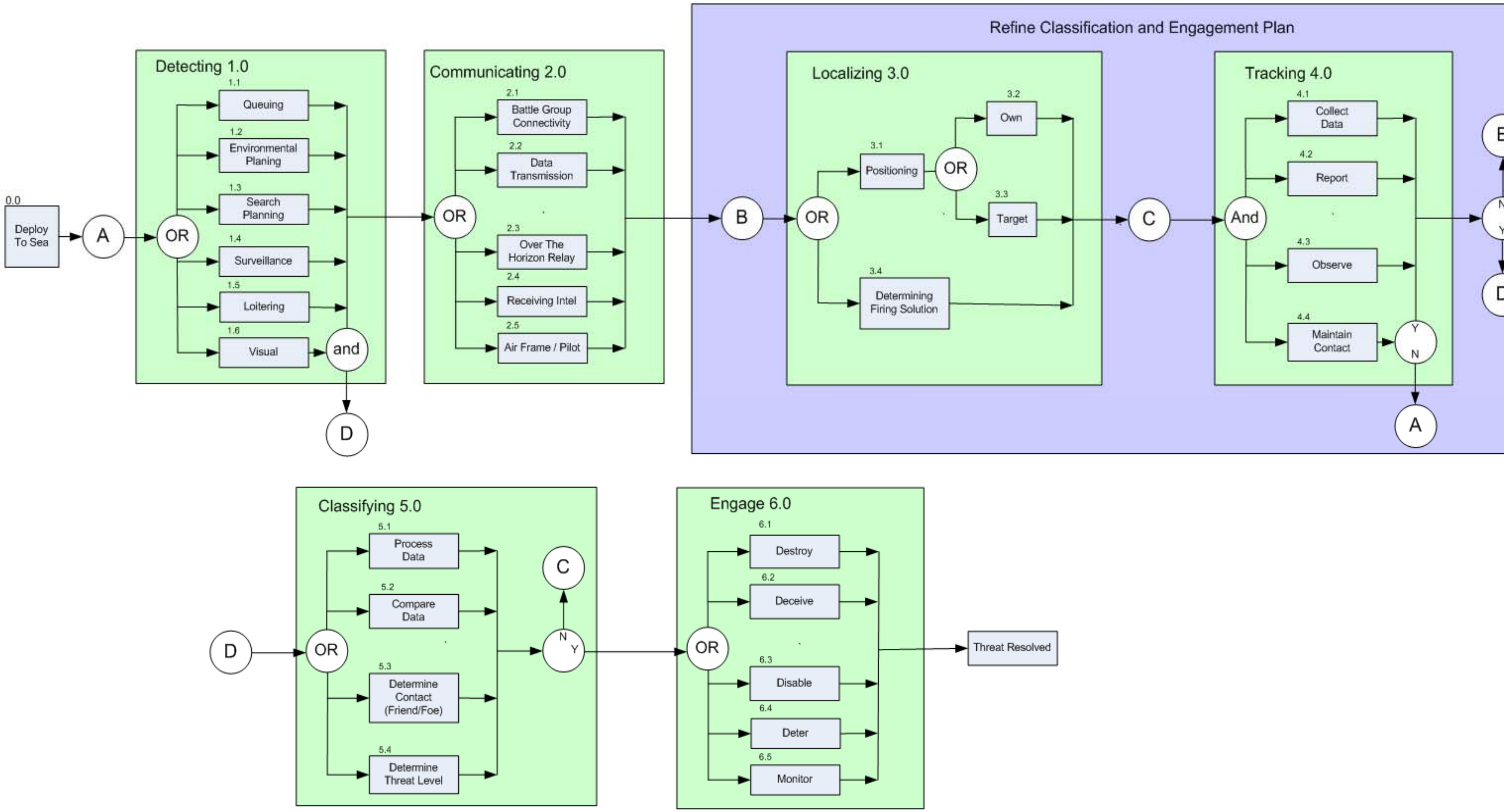


Figure 6. Functional Flow.

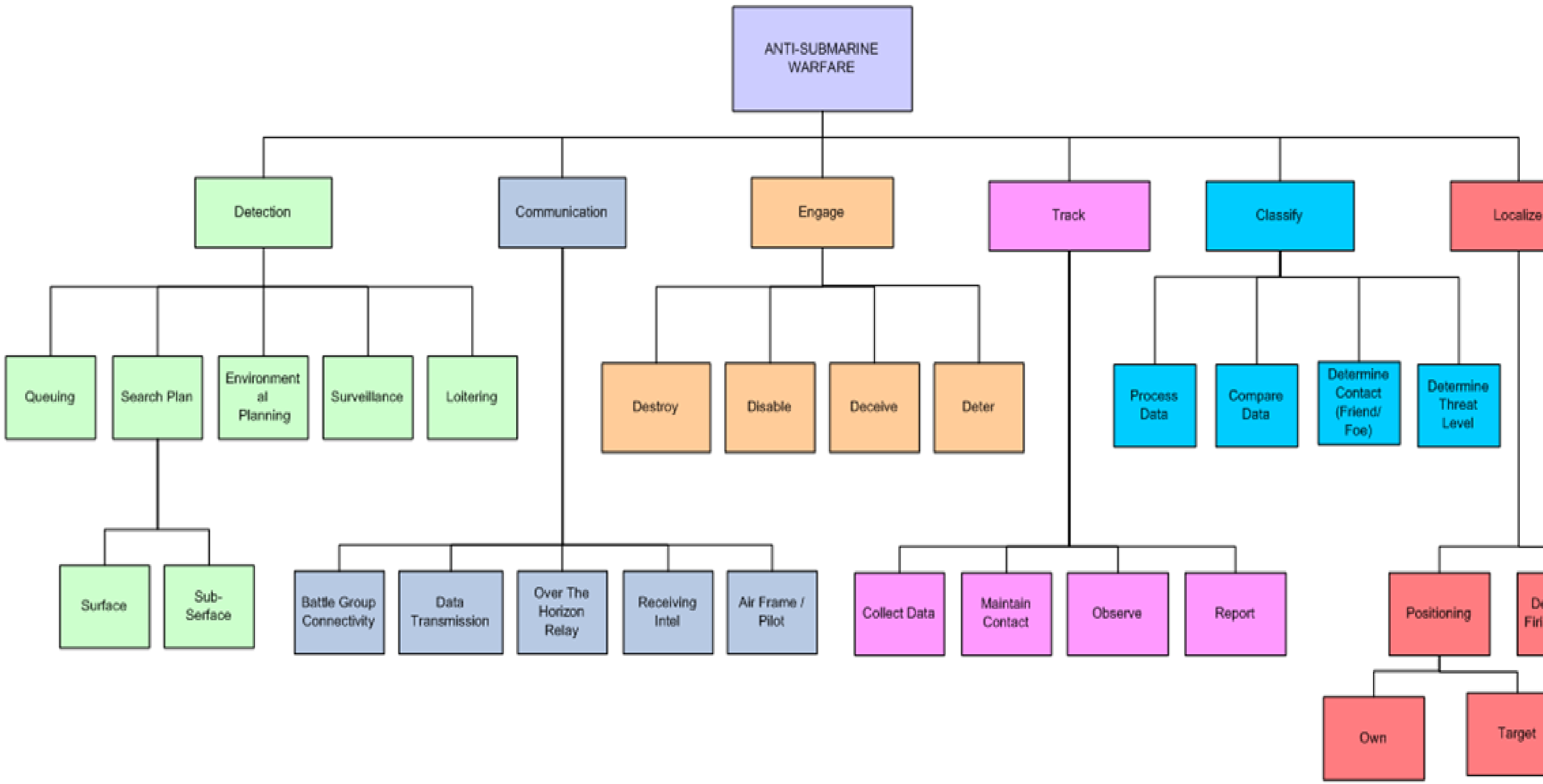


Figure 7. Functional Hierarchy.

C. REVISED PROBLEM STATEMENT

Based on the results of the needs analysis, the team updated the initial problem statement and established the following revised problem statement, or effective need for the HAMR ASW mission module:

> "A persistent airborne asset for detecting, communicating, tracking, localizing, classifying and engaging ASW threats."

This statement captures the functional requirements and objectives of the system.

D. VALUE SYSTEMS DESIGN

1. Value Structure

The value structure design methodology and purpose is described by the following:

"The construction of value hierarchies reflects the values of our critical stakeholders by expanding the effective need of our system into critical functions, sub-functions and objectives of our system. *This is the foundation of the Value System Design step of the Problem Definition phase of the SEDP*…The completed value model is the mechanism that we will use is to evaluate how well each alternative meets our clients' needs."[38]

This value structure provides a top down view of what is to be accomplished, the relative value of those accomplishments, and by what means they will be measured. The effective need was given earlier and will be the foundation for the value structure.

For clarity the following definitions will be used when discussing these terms:

*Function***:** An activity that the system is designed to perform (i.e. *Destroy targets*) and an evaluation consideration for alternative system designs.[39]

---

[38] Paulo [2006]
[39] Paulo [2006]

*Objective***:** Preferred direction of attainment of an evaluation consideration, or functional capability (i.e. *Higher probability of kill*).[40]

*Measure of Effectiveness (MOE)***:** Scale, or metric, used to measure the degree that attains an objective (i.e. *Probability of kill*).[41]

2. Process

Building the objectives hierarchy began with the functions identified in the functional hierarchy. Stakeholder feedback, team research, and SME interviews were used to identify objectives and associate them with high level functions. The high level function of prosecution was added to reflect the relationship between the classify, track, localize, and engage functions as well as further emphasize the importance of the detection function. Functions that were not included in the functional analysis were also added for suitability items that are essential to the development of the module. Human factors were added to reflect stakeholder interest in reducing system manning. Supportability, reliability, maintainability, availability, and survivability are not linked to primary objectives to be addressed in this paper. These suitability items are included in the value structure because they represent important functions of the proposed system, however due to the limited scope of this paper and direction from stakeholders, detailed analysis will not be undertaken for these functions and they will not be considered in the multi-attribute decision analysis.

Once the objectives were identified, MOEs were established for each objective. These MOEs were often directly called out in the objective or recommended by stakeholders. A few objectives were subjective by nature and did not have a universally agreed upon "best method" for measuring success. In these cases the team discussed known alternative methods and selected the method(s) that seemed most applicable and appropriate.

Maximize Probability of Detection: It is a primary objective of the system to, given a scenario, maximize the probability that an enemy submarine will be detected. This was broken down into sub-objectives of "maximizing detections" made while on

[40] Ibid [2008]
[41] Ibid [2008]

station and "maximizing time on station" to allow more opportunity to accomplish the objective. The MOEs for this objective are the percent of enemy submarines detected in relation to the number of total opportunities and the time on station per sortie of the system.

Maximize Detection Range: Maximizing detection range is fundamental to the ability of the system to be effective in operational scenarios. The unique properties of the ocean environment dictate that there are different operational areas that will have varying effects on the detection range of the system. The three primary operating areas of a submarine are on the surface, below the surface but above the thermal layer, and below the thermal layer. Each of those operational areas are considered as part of this objective. The MOEs for this objective are the detection ranges when an enemy submarine is operating in each of those operating areas.

Quickly Classify Contacts: In order to know what action needs to be taken when a submarine is detected and to ensure detected submarines, called contacts, are not prosecuted unnecessarily, they must be classified as quickly as possible. The MOE for this objective is time from first detection to classification.

Accurately Classify Contacts: In order to most efficiently use limited assets and prevent fratricide it is essential that contacts are correctly classified. The classification MOE is the error rate in all classifications.

Maintain a Firm Track: Having a track on a submarine means knowing within a reasonable certainty where that submarine is and where it is going, and maintaining that knowledge is essential to prosecuting the submarine. The MOE for this objective is the percentage of time that the track is maintained related to the time that the system is required to track the submarine.

Track Multiple Targets: Tracking multiple targets simultaneously is fundamental to the success of the system in all situations where multiple enemy contacts are present. The MOE for this objective is the number of contacts simultaneously tracked.

Reduce Area of Uncertainty: The area of uncertainty is the area in which you can say with confidence where the enemy submarine is. This objective reflects the need to

reduce that area as much as possible. This is especially important when the ultimate objective is to engage the enemy submarine. The MOE for this objective is the average area of uncertainty of enemy submarines at the time of firing point procedures.

Increase Standoff Distance: The further the enemy submarine is from the HAMR the less likely it will be to detect its presence and take evasive actions. The MOE for this objective is the average distance of the HAMR at the time of firing point procedures.

Reduce Time from Track to Firing Point Procedures: In order to transition from passively tracking an enemy submarine to beginning firing point procedures and conducting engagement activities, the area of uncertainty must be reduced sufficiently. It is important that this process proceeds as quickly as possible. The MOE for this objective is the time from track to firing point procedures.

Maximize Probability of Kill: Probability of kill is the MOE that represents a systems effectiveness in destroying enemy submarines.

Maximize Ability to Alter Enemy Mission: There are situations where the HAMR could be called upon to engage an enemy but not seek to destroy it. In those situations the goal is to harass the enemy and force them to alter or terminate their mission. The MOE for this objective is the percentage of enemy missions altered and assumes knowledge of the enemy mission.

Decrease Time to Kill: Reducing the time required to kill an enemy submarine increases the overall effectiveness of the system by reducing the enemy's ability to react and evade and increasing the ability of the HAMR to prosecute more targets in less time. The MOE for this objective is the time from when a firing solution is acquired and the enemy submarine is destroyed.

Effectively Communicate with Friendly Forces and Allies: Communication on data and command networks is essential to the effective execution of the mission of the HAMR with the ASW module. This is also identified as an area where the HAMR could provide a significant increase in the overall ASW capability of the Navy. In order to effectively communicate it is important that the communication networks be continuously available and that the range of be extended as far as possible. There are a large number

of communication formats and systems operating over multiple frequency bands. The MOEs for this objective are the availability of the individual systems, the range of the individual systems, and the percentage of systems that the system will include relative to the number of systems currently in use by the U.S. Navy and its allies.

Reduce Required Manning: Reducing required manning has many advantages and benefits, and stakeholders specifically expressed an interest in an unmanned alternative. Reduced manning is especially important for the HAMR ASW module since, due to its extended persistence, it will be required to carry multiple crews. The MOE for this objective is the minimum crew size per shift.

Table 1. Value System

Function/Sub-Function	**Objective**	**Sub-Objective**	**Measure**
Detect	Maximize Probability of Detection	Maximize Detections	Percent Detected
		Maximize Persistence	Time on Station
	Maximize Detection Range	Maximize above Layer Range	Detection Range above Layer
		Maximize below Layer Range	Detection Range below Layer
		Maximize Surface Range	Detection Range of target Periscope on Surface
Prosecute/Classify	Quickly Classify Contacts		Time from First Detection to Classification
	Accurately Classify Contacts		Classification Error Rate
Prosecute/Track	Maintain a Firm Track on Contacts		Percentage of Time Track Maintained
	Track Multiple Targets		Number of Simultaneous Contacts Maintained
Prosecute/Localize	Increase Standoff Distance		Average Distance at Time of Firing Point Procedures
	Reduce Area of Uncertainty		Average Area of Uncertainty

	Reduce Time from Track to Firing Point Procedures		Average Time from Track to Firing Point Procedures
Prosecute/Engage	Maximize Probability of Kill		Probability of Kill
	Maximize Ability to Alter Enemy Mission		Percent of Missions Altered
	Decrease Time to Kill		Average Time from Firing Solution to Kill
Communicate	Effectively Communicate with Friendly Forces and Allies	Carry All Systems Necessary to Communicate	Completeness of Communication Capabilities
		Maximize Availability of Networks	Availability of Communication Networks
		Maximize Range of Communication Networks	Range of Communication Ccapabilities
Supportability			
Maintainability			
Reliability			
Survivability			
Availability			
Human Factors	Reduce Required Manning		ASW Module Minimum Crew Size

3. Key Functions

Key functions, or key parameters, are defined as those functions that most clearly define the capabilities and characteristics that are most important to the success of the intended mission.[42] The stakeholder analysis and research performed earlier revealed certain functions that were viewed as being critical to the success of this system in performing its mission and meeting the ASW need of the Navy.

Initially it was unclear what the stakeholders envisioned as being the key functions of this system; there were many conflicting opinions about the direction the development should take. As the discussion went on and the scope of the system was

[42] CJCSM 3170.01C, Enclosure B, [2007]

more clearly defined, the stakeholders, especially users, began to emphasize a common message: "…we have assets for killing enemy submarines if we know where they are, the problem is finding them."[43] It was the opinion of most of the stakeholders that while the HAMR could, and perhaps should, be capable of performing attack missions, its true potential lay in its persistent search capabilities. The following statements capture this idea:

> "We need to convince the acquisition establishment that aircraft carriers cannot be defended against the threat of submarines unless protected by long endurance, low altitude, low stall speed aircraft, with large sensor payloads optimized for ASW operations."[44]
>
> "A large gap exists between the number of missions that need to be flown and the platforms available to execute them. The hybrid would relieve this pressure by taking on the patrol/escort missions that do not require great speed of flight but do require long term persistence with 24/7 coverage being the goal."[45]

4. Value Weighting

Taking into consideration all of the research and inputs provided, weights were assigned to each function, objective, and sub-objective, in the value structure. The weights can be represented in two different but related ways: local and global. Local weights are presented with each of the categories and subcategories requiring values that sum to 1. In other words, when summed, all of the weights for all of the functions, all of the objective weights under a single function, and all of the sub-objective (if applicable) weights of a single objective total 1. Global weights are the product of the local weights of an item and all of its parents, so for each category (function, objective, sub-objective) in the value structure, the sum of the global weights for all items is 1. These weights establish the relative importance of each item in the value structure and are used in the multi-attribute decision analysis to assign the proper weight to the outcome of a certain function or objective as it relates to the overall system effectiveness.

[43] CAPT Kuhlman [2008]
[44] Statter [2008]
[45] Allocca [2008]

The process for establishing weights included several iterations and revisions. In order to initially establish the weights, the project team met together and assigned values based on the understanding they had gained about the desired outcome. Upon finishing the initial weighting of the value structure it was shown to and discussed with several key stakeholders. Changes were made based on the stakeholder feedback, and after the structure had been fully revised, it was again submitted to the key stakeholders for review. When the stakeholders were satisfied with the weighted value structure, it was considered complete. Figures 8 through 15 show the value structure functions and objectives in a hierarchy with their associated weights in parenthesis (local/global).

The global weights shown in Figures 8 through 15 reflect the importance of detection as the key function and the decision not to include some of the suitability items in the decision analysis. Because of emphasis on the tactical performance and the transitional nature of this technology, the opinion of the team, the project stakeholders, and advisors was that, except for communication capabilities and reducing manning through human systems integration, suitability factors need not be considered in the analysis. As mentioned previously, these suitability items are included here to emphasize that. While they may not have immediate value, they are important and will have significant value in future development of this technology.

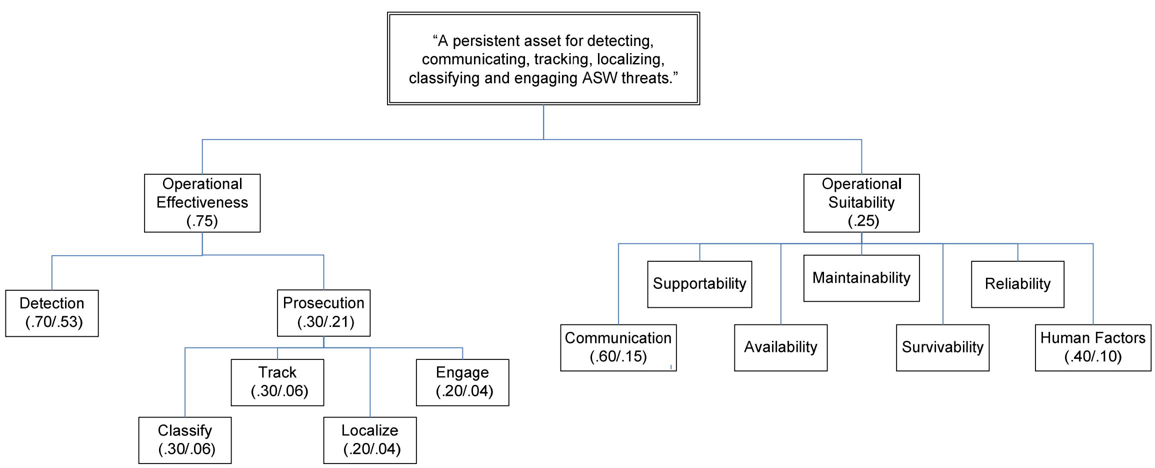


Figure 8. Objectives Hierarchy.

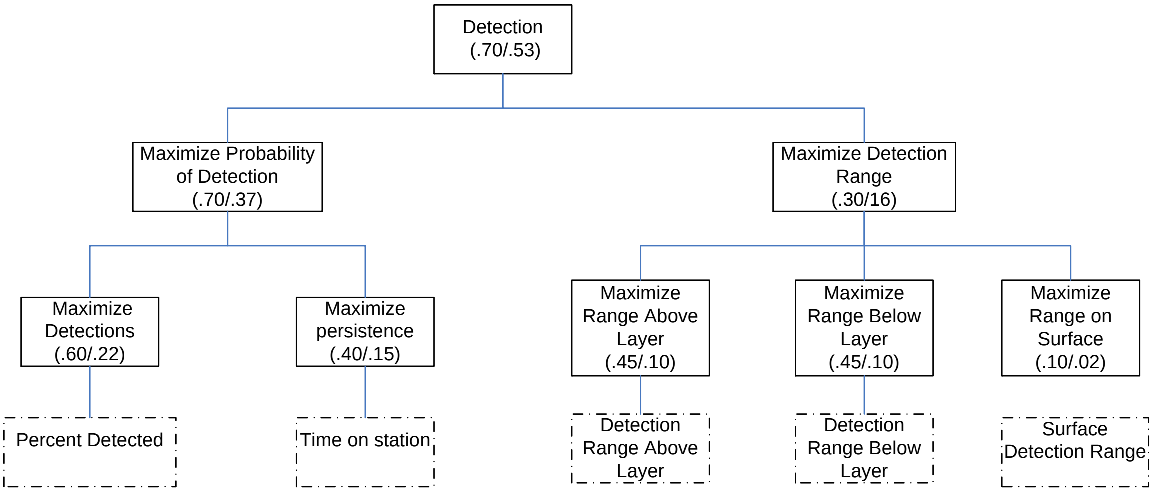


Figure 9. Detection Branch.

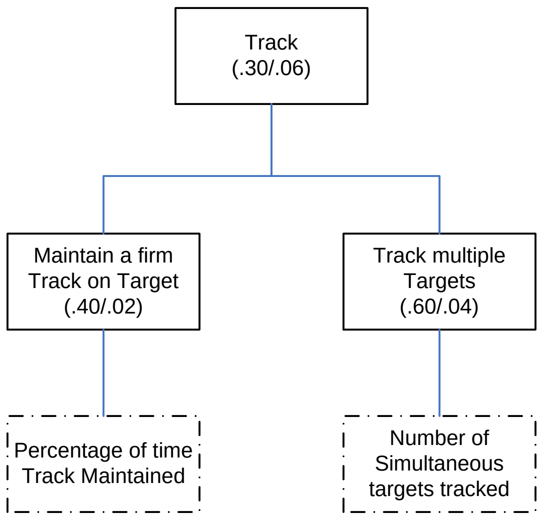


Figure 10. Tracking Branch.

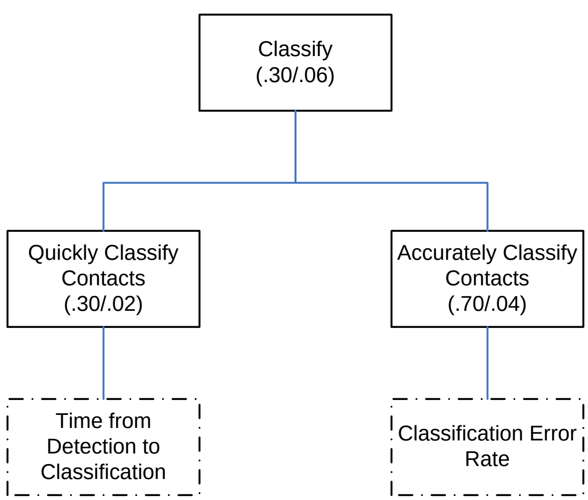


Figure 11. Classify Branch.

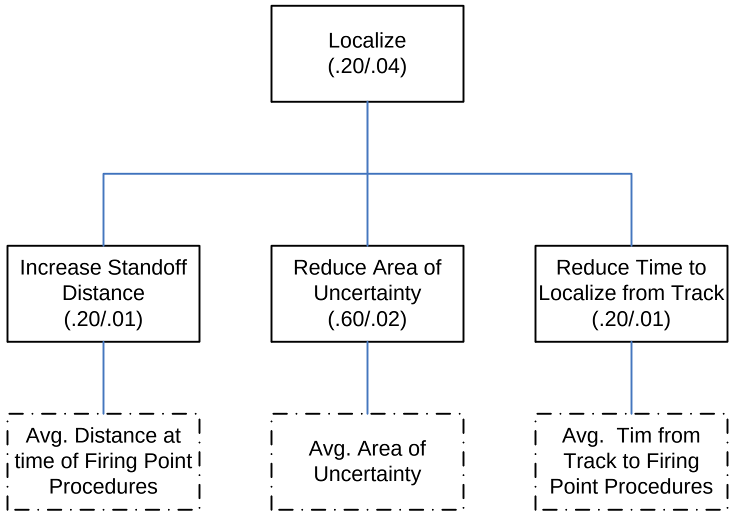


Figure 12. Localize Branch.

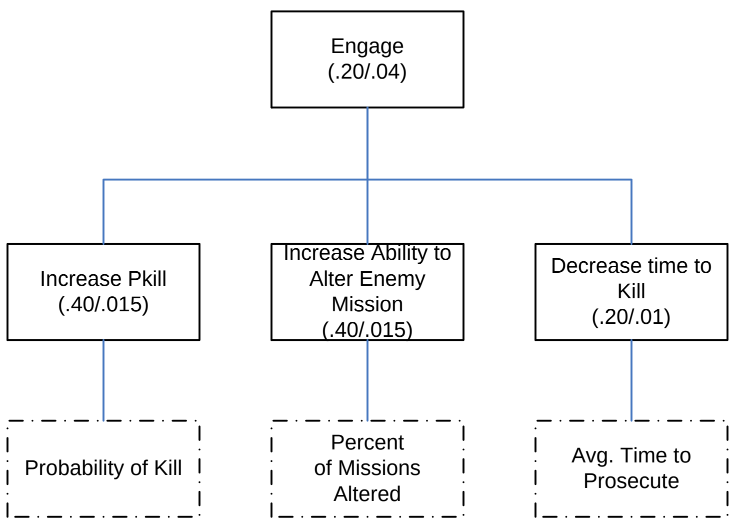


Figure 13. Engage Branch.

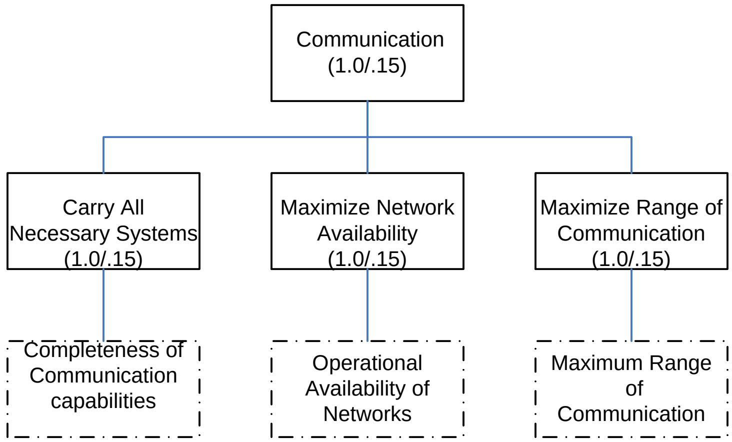


Figure 14. Communication Branch.

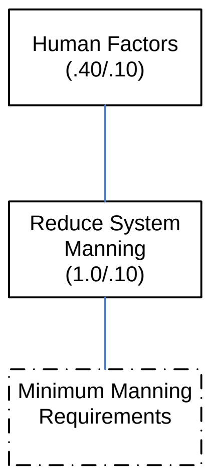


Figure 15. Human Factors Branch.

5. Value Curves

In order to asses the value of raw data generated from analysis and simulation activities and incorporate it into the value structure, value curves are needed. Value curves help show the relative value of data by assigning a value score to the entire range of possible outcomes. Each value curve is represented graphically by plotting the possible outcomes on the horizontal axis versus the relative value on the vertical axis. The relative value is a decimal value between 0 and 1.

There are many different methods for establishing value curves presented in literature. The team used a two step approach to elicit value curves for the MOEs to be used in the multi-attribute decision analysis. The first step is selecting endpoints for the

value curve and the second is eliciting the relative values of the possible range of data points. Establishing the end values of the curves was done through a process of combining data from analysis, simulations, and information from stakeholders and SMEs. In most cases, the most simple and verifiable endpoint values represented the two extremes that an MOE could obtain, often referred to as the "Ideal Range Method."[46] Once the endpoints were established, again using the process of combining data from analysis and simulations and direct elicitation from stakeholders and SMEs,[47] value curves were developed and incorporated into the multi-attribute decision analysis.

Modeling and analysis is performed to generate data for the MOEs in the value structure. Limitations in available information, the classified nature of much of technical and performance information, and the fact that the scope of this paper does not include any actual hardware design or "man-in-the-loop" simulations meant that obtaining data for each of the MOEs would not be practical or feasible. The simulations, models, and analysis were focused on producing MOEs that best captured the broadest range of objectives and provided data for those objectives determined to be of the most valuable. Ultimately what this means is the MOEs presented in the multi-attribute decision analysis will not represent the complete set of MOEs presented in the value structure, but rather the decision analysis will include MOEs generated as a result of modeling simulation and analysis activities. Because the value curves are dependent on the data that is produced as a result of modeling and analysis, the value curves and the associated MOEs and data will be presented and discussed in greater detail in Section IV.

[46] Paulo [2006]
[47] Sage[2000:p.404-405]

III. DESIGN AND ANALYSIS

A. ALTERNATIVES GENERATION

The alternatives generation phase is when the team begins to answer the question 'How is the team going to meet the needs of the customer?' During this phase, the design team did not limit itself to a certain methodology or idea but tried to come up with as many unique solutions as possible. This section discusses some of the proposed solutions and then uses the information gathered earlier to identify which of these alternatives are viable. The alternatives that the team finds to be viable will be the recommended alternatives discussed in chapter V.

The project team was tasked to design a system that will utilize existing ASW assets to act as a force multiplier in ASW thus expanding the current ASW capability. The alternatives generation portion of the project included exploring the ability to utilize the current government off-the-shelf (GOTS) systems. GOTS takes existing ASW systems and integrates them into a new HAMR ASW module that will be suspended from the HAMR vehicle. The team evaluated alternatives from ASW systems deployed on U.S. Navy submarines, aircraft, and surface ships to determine which systems are suitable for integration into the HAMR ASW module.

Physically, the system is bounded primarily by the capabilities, configuration, and interface of the HAMR airframe. The ASW module is intended to be capable of being attached, detached, and stored with relative ease.

B. DEVELOPMENT OF ALTERNATIVES

Development of alternatives is a process of bringing system alternatives into being, which is often referred to as an ideation process, or "the creative mental process of producing concepts and ideas in order to solve problems."[48] The design team identified the critical functions and sub-functions of the proposed HAMR ASW module using brainstorming and Zwicky's Morphological Box to generate a list of four design alternatives.

The team considered the operational scenarios that the HAMR would be tasked to perform. Current ASW systems were researched and compiled in a master list. Once the master list was complete the systems were divided into five categories:

- Combat systems/Communications
- Hard kill (HK) weapons
- Soft kill (SK) weapons
- Subsurface sensors
- Surface sensors

This capability is intended to be fielded within five years for this purpose. Emphasis was placed on fielding an operational unit and less emphasis was placed on advanced technology. The list of criteria used when determining the various alternatives is listed in Table 2. This project is focused on the design of an ASW module, as such any hotel accommodations required for the personnel required to operate the module is assumed to be accommodated by the HAMR and is outside the scope of this report.

[48] SE 4001 [2008:p.5]

Table 2. Criteria Used.

Criteria	Description
Technology Readiness Level (TRL) 5	The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment.
Timeliness	System can be fielded in five years.
The weapon system leaving inventory	The weapon system must not be at end of life cycle. ex: would not consider MK 50 torpedo since it will be out of the fleet in FY12-14.
Component applicability	The component is required to fulfill a HAMR ASW requirement.
Ineffectiveness	Components from other systems that do not apply to the ASW mission.
Replaced by newer component	Assets from the Navy inventory that has been replaced by a newer model.

Once the initial four alternatives were determined, the team performed some regrouping of similar functions and put them under the higher level category of combat systems. This allowed the team to plot the four alternatives in a Zwicky's Morphological Box and resulted in five functional areas as shown in Figure 16.

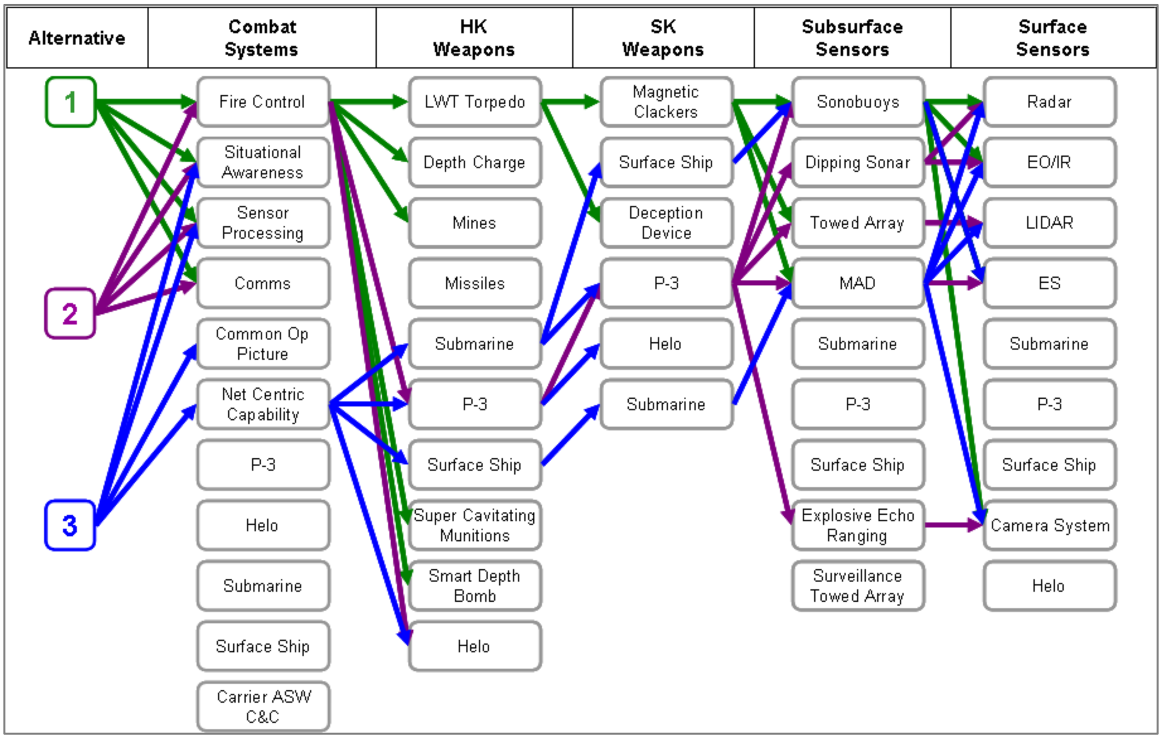


Figure 16. Zwicky's Morphological Box.

After much research and discussion the team was able to take the various ASW systems and determine four design alternatives to be considered.

1. Alternative #1

The first design alternative, 'Single Platform with Stand Alone Operations' is intended to perform detection, tracking, and prosecution functions. It is called the "single platform" since it does not rely on any other systems external to the HAMR to perform the capability. The detection capabilities that are performed include 1,080 sonobuoys, and the prosecution capability is supported with the use of MK-54 torpedo's, super cavitating munitions, smart depth bombs, and RAMICS. The complete list of systems included with this alternative is shown in Table 3. The quantity of sonobuoys was determined by the number required to sustain a tracking mission for the maximum duration of 7 days that the HAMR would be able to support, the active lifespan of a sonobuoy (8 hrs), the number of sonobuoys deployed (50 ea.) at a time to enable tracking,

and onboard spares (30 ea.) in case of failure. Based on the list of systems included in this alternative, it was determined that it will require four people to operate the system at any given time. Assuming an 8 hour shift, there would need to be twelve people onboard the HAMR to support this system. This alternative does, however, include 8 lightweight torpedoes. This number was determined since the ASW module utilizes existing systems, and the P-3 torpedo magazine is designed to hold 8 torpedoes.

Table 3. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Subsurface Sensors	Surface Sensors
Torpedo Preset System (MK437)	Lightweight Torpedo (MK54)	Magnetic Anomaly Detector (AN/ASQ-233)	Surface Search Radar, Periscope (APY-10)
TIS – SAAS & SPS	Super Cavitating Munitions (MK258)	Passive Sonobuoy (SSQ 53F)	LIDAR (April Showers)
GCCS-M (USQ-119)	Smart Depth Bomb (Modified JDAM) (MK 82/BLU-111)	Active Sonobuoy (SSQ 62E)	EOIR HD Telescope Camera (Star SAFIRE III)
Link 16 (AN/URC-107(V))	RAMIC (AN/AWS-1)	ADAR Sonobuoy (SSQ 101)	ESM (AN/ALQ-217)
SATCOM (PRC-117F)		EER Sonobuoy (SSQ 110)	
Automated Digital Networked System (ADNS)			
Sonobuoy Receiver (ARR 970)			
Sonobuoy Dispenser (Integrated with TIS)			

2. Alternative #2

The second design alternative is the ‘Heavy Weight (HWT) Sensor Platform with Towed Array and Cooperative Engagement Operations.’ This alternative is intended to use the HAMR for detection and tracking, however it will use external systems such as the P3 or H-60 for prosecution. The combat systems category remains the same as with the first alternative. In the subsurface sensors category the team has added a towed array

and dipping sonar to the list. The complete list of systems included with this alternative is shown is Table 4 below. This alternative has the same number of sonobouys as with Alternative 1 and is designed to sustain the same 7 day duration that the HAMR would be capable of sustaining. Even though the design has different systems included, the total number of persons required to operate it remain the same (four per shift).

Table 4. Heavy Weight (HWT) Platform List of Systems.

Combat Systems	**Hard Kill The weapons**	**Subsurface Sensors**	**Surface Sensors**
Torpedo Preset System (MK437)	Lightweight Torpedo (MK54) via P-3	Magnetic Anomaly Detector (AN/ASQ-233)	Surface Search Radar, Periscope (APY-10)
TIS – SAAS & SPS	Lightweight Torpedo (MK54) via CH-60	Passive Sonobuoy (SSQ 53F)	LIDAR (April Showers)
GCCS-M (USQ-119)		Active Sonobuoy (SSQ 62E)	EOIR HD Telescope Camera (Star SAFIRE III)
Link 16 (AN/URC-107(V))		ADAR Sonobuoy (SSQ 101)	ESM (AN/ALQ-217)
SATCOM (PRC-117F)		EER Sonobuoy (SSQ 110)	
Automated Digital Networked System (ADNS)		Thin Line Towed Array (TB-29A)	
Sonobuoy Receiver (ARR 970)		Towed Array Handler (OA-9070B)	
Sonobuoy Dispenser (Integrated with TIS)		Dipping Sonar ALFS	

3. Alternative #3

The third design alternative is the ‘Unmanned Light Weight (LWT) Sensor Platform with Buoys and Cooperative Engagement Operations.’ This alternative is similar to Alternative 2 except that it does not have the towed array or dipping sonar. Since there are no prosecution capabilities with this alternative and any towed array or dipping sonar, the manning requirements of this solution are very low. There is the possibility since it is primarily a sensing system that the system could be operated

remotely and would not require any onboard manning. The complete list of systems included with this alternative is shown is Table 5 below. Even though this is an unmanned alternative and no personnel are required to be onboard the HAMR to operate the ASW module, it was determined that the system would still require two people to operate this system located on the ground or other Naval vessel.

Table 5. Unmanned Light Weight (ULWT) Platform List of Systems.

Combat Systems	**Hard Kill The weapons**	**Subsurface Sensors**	**Surface Sensors**
TIS – SAAS & SPS	Lightweight Torpedo (MK54) via P-3	Magnetic Anomaly Detector (AN/ASQ-233)	Surface Search Radar, Periscope (APY-10)
GCCS-M (USQ-119)		Passive Sonobuoy (SSQ 53F)	LIDAR (April Showers)
JTRS (PRC-148)		Active Sonobuoy (SSQ 62E)	EOIR HD Telescope Camera (Star SAFIRE III)
Link 11 (AN/URC-125)		ADAR Sonobuoy (SSQ 101)	ESM (AN/ALQ-217)
Link 16 (AN/URC-107(V))		EER Sonobuoy (SSQ 110)	
Link 22			
Class I CDL			
SATCOM (PRC-117F)			
Automated Digital Networked System (ADNS)			
Sonobuoy Receiver (ARR 970)			
Sonobuoy Dispenser (Integrated with TIS)			

4. Alternative #4

The fourth design alternative is the current Navy P-3 ASW operations. With this alternative the team would not build an ASW module for the HAMR, rather the ASW mission would be performed by the P-3 platform and other current ASW systems. This alternative is shown in Table 6. This alternative is used as a baseline for comparing the various alternatives. It was determined that the P-3 requires six people onboard the aircraft to operate the ASW systems, and it carries one torpedo magazine which holds eight torpedoes.

Table 6. P-3 ASW Platform List of Systems.

Combat Systems	Hard Kill The weapons	Subsurface Sensors	Surface Sensors
Link 16 (AN/URC-107(V))	Lightweight Torpedo (MK46)	Receiver-Counter Sonobuoy (AN/ARS-5)	Periscope Radar
Electro-Optical, Rapid Targeting System (RTS)	Advanced Lightweight Torpedo (MK50)	Bathythermograph Sonobuoy (AN/SSQ-36)	EOIR
AN/ALQ-78A or ECP	Lightweight Hybrid Torpedo (MK54)/HAAWC	Sonobuoy (AN/SSQ-53D/E)	Magnetic Anomaly Detection (MAD)
	Encapsulated Torpedo (MK 60)	Sonobuoy (AN/SSQ-57B)	AN/APS-137(V)5 Radar
	Harpoon Stand-off Land Attack Missile (SLAM)	Sonobuoy (AN/SSQ-101)	
	IR Maverick Missile	Sonobuoy (AN/SSQ-110A EER)	
		Sonobuoy AN/SSQ-86	
		Sonobuoy AN/SSQ-62B/C/D/E	
		Sonobuoy AN/SSQ-77B	

C. MODELING AND ANALYSIS

1. Performance Analysis

a) Approach and Methodology

The purpose of modeling the HAMR alternatives was to provide objective input into the alternatives selection process of the SEDP. Therefore, key measures of evaluation were selected as desired outputs of the modeling and simulation effort.

The operational effectiveness modeling effort for the HAMR ASW module project first established performance of the existing P-3C Orion ASW system in the context of a sample mission accomplishment. With the results of those scenarios, further analysis established the performance of the three various HAMR ASW configurations in the context of the chosen mission scenarios.

The modeling and simulation effort included three major phases: modeling, simulation, and analysis. The modeling and simulation was accomplished utilizing the Naval Simulation System (NSS) software package and Microsoft Excel. Further analysis was accomplished utilizing Minitab 15.

Overall, three modeling objectives were established:

- Develop analytical models of various alternatives
- Develop quantitative operational scenarios
- Determine performance characteristics of various alternatives within the developed scenarios

b) Modeling and Simulation Software

The principal tool the HAMR modeling team utilized for operational effectiveness modeling and analysis was the Naval Simulation System (NSS) software package, developed by the Space and Naval Warfare Center (SPAWAR) PD-15 and Metron Inc. "The Naval Simulation System (NSS) is an object-oriented Monte Carlo modeling and simulation (M&S) software package. NSS is designed to support operational commanders in developing and analyzing operational courses of action at the mission, group, or force levels."[49] The HAMR team utilized the platform level modeling

[49] Metron [2002]

capability of NSS as the primary tool for analyzing the operational capability of the three HAMR alternatives.

c) Modeling and Simulation Measures of Evaluation

Using the measures of effectiveness and performance that were developed in the objectives hierarchy, the HAMR modeling team established evaluation metrics which could be obtained utilizing the available modeling resources. Three of the first tier functions on the HAMR ASW functional hierarchy were chosen to be represented in performance modeling. The detection function was selected, represented by probability of detection. The engage function was selected to be modeled, represented by time to engage. The track function was also selected and modeled by a time which the system is capable of tracking a contact. Each of these measures encapsulate different characteristics of the performance of the system.

d) Model Input and Assumptions

The object oriented design of NSS allowed the team to share components across models. A principal design goal of the model object generation was to reutilize and leverage existing NSS objects throughout the modeling effort. The platform details for the P-3C Orion were leveraged to build the various HAMR platform configurations. Re-utilizing the existing P-3C Orion platform model and sharing sensor objects across airframes ensured that each configuration had equivalent component capabilities and increased the manageability of the modeling effort. Table 7 shows key model differences among the various platforms.

Table 7. Model Inputs.

Platform	Key Model Difference	Description
P-3	Baseline	8 MK-54 torpedoes 328 NM/hr cruise speed 100 sonobuoys
HAMR-1	Slower	8 MK-54 torpedoes 75 NM/hr 1080 sonobuoys
HAMR-2	Towed Array	TB-29A towed array No torpedoes 20 NM/hr top speed when using TB-29A
HAMR-3	More Sonobuoys	Greater sonobuoy capacity can double acoustic sensor coverage. 75 NM/hr No torpedoes

The command structure for the BLUE forces was represented the same in each scenario. A naval commander is the overall authority for the scenario. This commander has two subordinate objects: the Naval Air Station and the ASW commander. The Naval Air Station is the container object for the collection of aircraft platforms. The ASW commander is the object which executes the ASW mission, drawing on the aircraft as resources. Figure 17 displays the force structure utilized. Each of the platforms modeled in the scenarios were assumed to have 100% operational availability. This ensured that the ASW mission would be executed as designed rather than be impacted by repair and replacement effects. Mean time between failure (MTBF) and mean time to repair (MTTR) are important when evaluating operations, but the study of those effects are well beyond the scope of this study. Additionally, communications between the ASW commander and the aircraft were guaranteed to be sent, meaning there were no lost messages when communicating detection events from aircraft to the ASW commander.

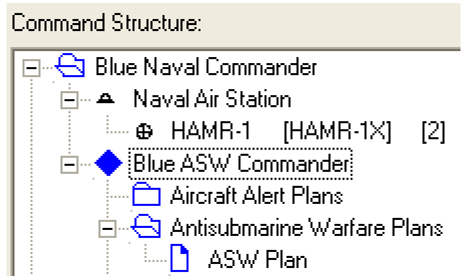


Figure 17. Scenario Force Structure. From NSS [2008].

e) Scenario Overview

Three operational scenarios were developed to examine the performance baseline ASW capability and three HAMR platform variants. Two of the scenarios were modeled in NSS, and the other scenario was examined utilizing spreadsheet analysis. Table 8 shows the various operational scenarios. Scenario ALPHA examines detection capability. Scenario BRAVO examines the effectiveness of the platform's ability to apply lethal force. Scenario CHARLIE examines tracking effectiveness.

Table 8. Operational Scenarios.

Scenario	Location	Description	Primary MOE	Duration	Tool
ALPHA	Korean Strait	75 NM barrier is laid across Korean Strait. One RED submarine is operating in the area. ASW platform reports detections of RED sub	Time tracked	7 Days	NSS
BRAVO	Korean Strait	75 NM barrier is laid across Korean Strait. Six RED submarines are operating in the area. ASW platform reports detections of RED sub. Armed ASW platform engages RED subs. Unarmed HAMR variants call for fire from P-3 assets at NAF Atsugi	Time to first shot	7 Days	NSS
CHARLIE	Philippine Sea	ASW platform tracks RED submarine from Korean Strait through Philippine Sea	Sorties	N/A	Excel

f) Scenario Alpha

The purpose of Scenario ALPHA is to measure detection capability. The performance model represented this indirectly by measuring the detection time a track on a contact is held. The ALPHA scenario involves a barrier search in the Korea Strait. The mission objective is to detect hostile submarine contacts (described herein as RED FORCES) that may be transiting the area. The barrier search region (Figure 18) is formed approximately 75 NM in length between the landmasses of the Republic of Korea and Japan by the aircraft under test (BLUE alliance). Air platforms are operating from Naval Air Station Atsugi. The BLUE asset is directed only to report detections of RED FORCE contacts to the ASW commander located at NAS Atsugi. The scenario is simulated for a period of 7 days.

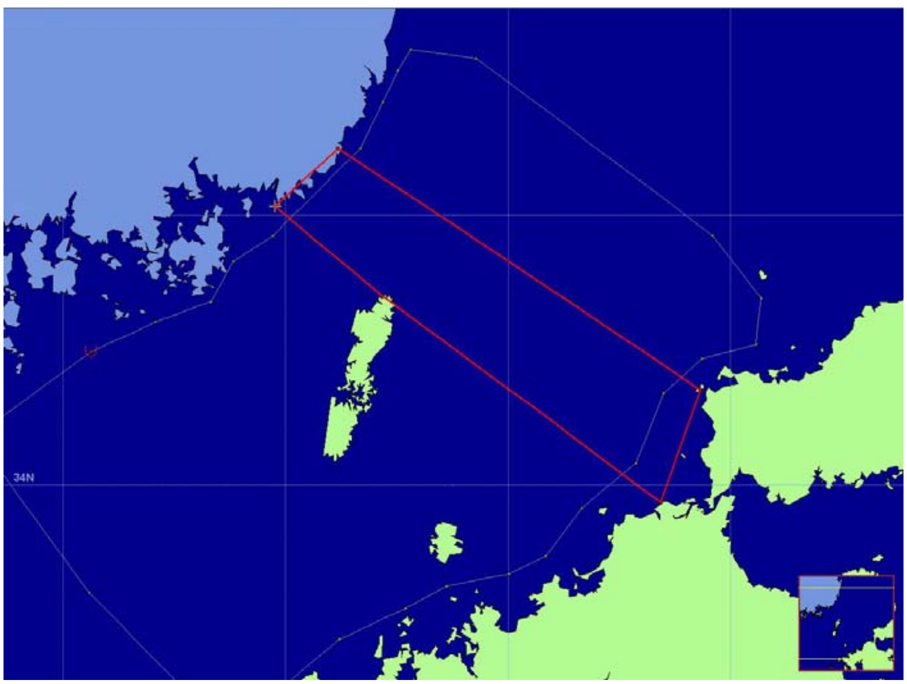


Figure 18. Map of Barrier Search Region. After NSS [2008].

Each of the four alternatives (P-3, HAMR-1, HAMR-2, and HAMR-3) was exercised in the ALPHA scenario. Most aspects of the operational characteristics of the alternatives remained constant across all platforms. Differences are shown in the

inputs on Table 9 shown below. Platform launch occurs only one time for the HAMR aircraft. The P-3's rotate on station for 14 hour periods. The sensor coverage and performance was the same for P-3 and HAMR-1, with a difference in buoy field deployment time. The simulated P-3 is capable of deploying a 30-buoy, 3-column, 10-row field in 1 hour 15 minutes. This deployment time is repeated by follow-on P-3 aircraft when the platform comes on station. The HAMR-1 and HAMR-2 deploy the same field in 2 hours. The HAMR-2 utilizes the additional towed array passive sonar sensor with a simulated max range of 10 NM. The HAMR-3 utilizes a larger sonobuoy search field due to its capacity to carry more buoys. The advantage of the 5 column, 10 row field is offset by a longer (5 hour) deployment time. For all platforms, buoy replenishment is implicit in the model and not tracked by NSS.

The RED submarine which is operating in the ALPHA scenario has active and passive acoustic vulnerabilities. The submarine also has additional "snorkel" vulnerability at 24 hour intervals for 30 minute durations. The motion plan specifies the RED submarine to operate in a fixed region, annotated by the red square (Figure 19), of approximately 15,000 NM^2.

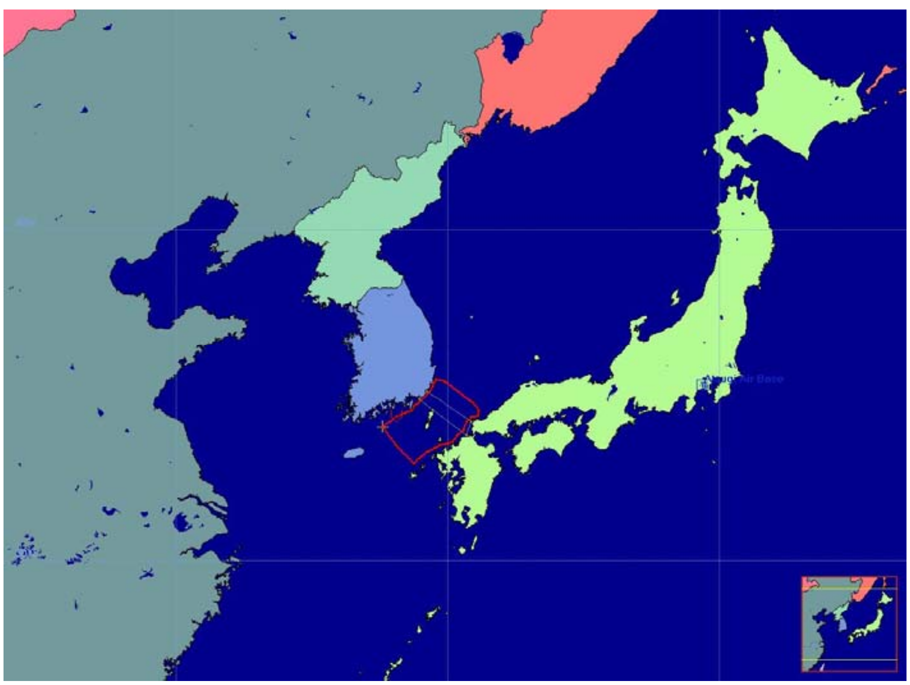


Figure 19. Map of Scenario Fixed Region. After NSS [2008].

The input parameters shown in Table 9 were utilized in the NSS simulation to determine values for detection and maintaining a track on the RED submarine. The description of the MOPs given in NSS is shown in Table 10.

Table 9. Scenario ALPHA Input Parameters.

Parameter	HAMR-1 TORPS	HAMR-2 ARRAY	HAMR-3 BUOYS	P-3
Aircraft Used	**1**	**1**	**1**	**2**
Sonobuoy MDR	**5 NM**	**5 NM**	**5 NM**	**5 NM**
Sonobuoy Coverage	**75 x 15 NM**	**75 x 15 NM**	**75 x 30 NM**	**75 x 15 NM**
Towed Array	**None**	**TB-29A**	**None**	**None**
Sonar Type	**Passive**	**Passive**	**Passive**	**Passive**
Buoys per Field	**30**	**30**	**50**	**30**
Ingress Time	**~2 hrs**	**~2 hrs**	**~2 hrs**	**~1.5 hrs**
Time to Deploy Field	**2 hrs**	**2 hrs**	**5 hrs**	**1.25 hrs**
Time on Station	**160 hrs**	**160 hrs**	**160 hrs**	**14 hrs**
Egress Time	**n/a**	**n/a**	**n/a**	**1.5 hrs**
Maintenance/ Refuel Time	**n/a**	**n/a**	**n/a**	**4 hrs**
Scenario Runs	**100**	**35**	**100**	**100**

Table 10. NSS Description of Measures of Performance.

MOE	Description
Total Tracking Time	Records the total time that tracks are held by tracking sensors. This means that for multiple tracks held simultaneously, the time recorded is the total length of time there is a track held. This total time is recorded at each point for which loss occurs for the last such track held or at the end of the scenario, whichever applies in that instance.

The results of scenario ALPHA shown in Table 11 indicated that the larger sonobuoy field afforded by the HAMR-3 greater carrying capacity increased its ability to detect and hold a track on the RED submarine. However, the doubling in size does not double the detection opportunity duration. This indicates that the RED

submarine operated outside of the barrier region for a majority of the scenario. It is important to note also that the difference in sonobuoy field deployment time did not appear to negatively impact HAMR-3's ability to detect a particular target. A slight increase in total tracking time is shown in HAMR-2's performance over HAMR-1. This slight difference can be attributed to the additional detection capability of the towed array. An even larger increase could be seen with HAMR-2 if the mission were tailored to utilize the towed array exclusively along the perimeter of the barrier region, rather than overlapping the existing coverage of the sonobuoy field. This would be a good candidate for further analysis in future runs of the scenario. Figure 20, tracking time intervals, shows the 95% confidence intervals for the mean tracking time.

Table 11. Scenario ALPHA Results.

Platform	Mean Tracking Time	Median Tracking Time
P-3	16.62	16.3
HAMR-1	18.08	16.1
HAMR-2	18.49	16.9
HAMR-3	30.57	31.1

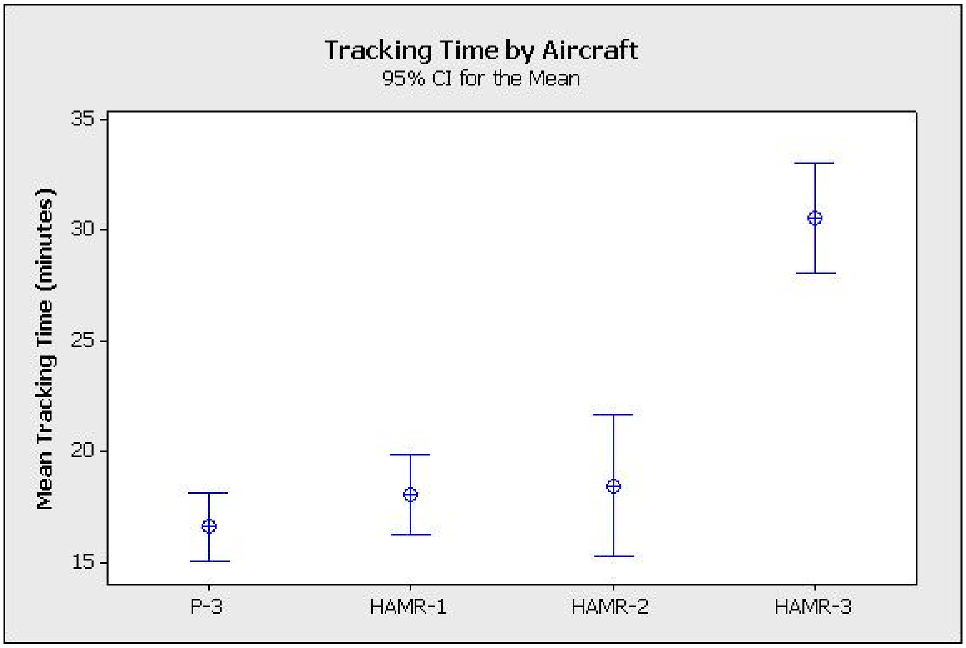


Figure 20. Tracking Time Intervals.

g) Scenario Bravo

Scenario BRAVO occurs in the same geographical region as scenario ALPHA. The mission objective was to engage RED FORCE subsurface contacts with lethal force. The various platforms search area was the same 75 NM barrier region specified in scenario ALPHA. When the RED submarine was detected, the platform began its engagement sequence if in range. The P-3's that were assigned to patrol the barrier region engaged the RED targets. Similar to the P-3, the HAMR-1 was afforded the ability to maneuver into position and engage directly when the submarine was identified. HAMR-2 and HAMR-3 utilized P-3's deployed from NAF Atsugi in order to prosecute targets.

Scenario Bravo was run multiple times in various configurations. This was done in order to examine the effect of varying numbers of RED submarine targets operating in within the region. Table 12, scenario bravo trials, summarizes the various trials that were conducted.

The MOP for scenario Bravo is the "Time to First Shot." This is defined as the difference in time from the first detection of an individual RED submarine$_i$, and the

time at which the first the weapon is launched against a submarine$_i$. As an example, in any given trial, any RED submarine will be detected once and only once. That same RED submarine will then be fired upon by the engaging asset. The times at which these events occur are then subtracted from one another to derive the "Time to First Shot" MOP. For each trial, j, as shown in Table 12, there will be $i \times j$ data points for that particular alternative and target combination. Table 13 shows the NSS description of MOP's used in the BRAVO scenario.

Table 12. Scenario BRAVO Trials.

RED SUBMARINE Count $_i$	Scenario Trials j	Data Points
6	100	600
2	100	200
1	248	248

Table 13. NSS Description of MOP's Used in BRAVO Scenario.

MOP	Description
First Detection	Records the time of the first detection event simulated to occur against the object identified.
First Weapon Launch	Records the time of the first the weapons launch events against a target.

The intention of utilizing the "Time to First Shot" MOP is to capture the various delays in engagement time of the different alternative platforms, particularly the difference of having the weapons onboard the air platform and having to call for fire from secondary assets. There are a number of concerns associated with this MOP, which will become evident as the data gathered through the various trials of the scenario are analyzed. The first concern is that detection does not necessarily begin the engagement sequence. For instance, if the RED submarine moves beyond the sensor coverage area and is sufficiently far from the air platform to evade further detection, that submarine may not be detected again for several days over the course of the seven day scenario. However, the "Time to First Shot" clock is still ticking. This effect can be seen in the extreme 4th quartile outliers for each of the platforms under examination. Further trials of this scenario would include more granular data elements to derive the "Time to First

Shot" MOP, which would better evaluate the performance of the various platforms engagement capability.

The P-3 and HAMR-1 are assigned to the fixed barrier region and do not pursue the target beyond that region. The HAMR-2 and HAMR-3 simply pass contact information to the air ASW commander at NAS Atsugi. The air ASW commander then alerts and launches engagement assets (P-3's). At this point, the engaging P-3's can pursue the target RED submarine outside of the assigned barrier region. The results of the Bravo scenario appear to be skewed in favor of the HAMR-2 and HAMR-3 platforms because of this capability. Further trials of this scenario would include either the restriction of responding assets to the assigned Barrier region, allowing the HAMR-1 and P-3's to leave the assigned barrier region, or perhaps pass contact data along to a simulated third party responsible for the area in which the RED submarine has taken refuge.

The input parameters listed in Table 14 were utilized in determining probabilistic values for detection and maintaining a track on an undersea contact.

Table 14. Scenario "BRAVO – 6 Red Subs" Input Parameters.

Parameter	HAMR-1	HAMR-2	HAMR-3	P-3
Aircraft Used	**1**	**1**	**1**	**2**
Primary Attack The weapon	**8 x Mk 54**	**2 x P-3**	**2 x P-3**	**8 x Mk 54**
Ingress Time	**~2 hrs**	**~2 hrs**	**~2 hrs**	**~1.5 hrs**
Time on Station	**n/a**	**n/a**	**n/a**	**14 hrs**
Egress Time	**n/a**	**n/a**	**n/a**	**1.5 hrs**
Pursue Beyond Region	**N**	**Y**	**Y**	**N**
RED Submarines	**6**	**6**	**6**	**6**

Tables 15-17 show processed results from the scenario runs. Average detect-to-engage time is the time in minutes from the first detection of a target until the time at which a weapon is fired at that same target. For all platforms, there appears to be

a long interval (~10 hrs.) from initial detection to first weapon release. This can be explained by the tactics that the various platforms are utilizing.

During the scenario, the sonobuoy field is laid across the straight. The platform monitoring the sonobuoy field may be at any physical location within that area of coverage. The result is that the RED submarine may be detected, yet the air platform is not within range of the RED submarine or the Area of Uncertainty (AoU) is too large to begin an engagement sequence. The initial detection is noted, and the "Time to First Shot" interval clock begins. At this point in the scenario, the RED submarine may leave the area of coverage. The ASW platform (P-3 or HAMR variant) continues to monitor the field but does not investigate or pursue the detected RED sub. Instead, the ASW platform continues its search pattern without regard for the distant detection.

The two platforms which have a self engagement capability also have the highest median "Time to First Shot" measures. The result is most likely due to the fact that these two platforms carry only 8 MK-54 torpedoes on each sortie. As a result, these two platforms are forced to return to base when the weapons' stores are exhausted. The cooperative engagement platforms (HAMR-2 and HAMR-3) have the benefit of calling fully armed P-3s each time an engagement occurs.

Table 15. Scenario BRAVO Basic Statistics - 6 RED Submarines.

Measure (N=600)	P-3	HAMR-1	HAMR-2*	HAMR-3
Median Time to first Shot (minutes)	176	593	80	80
Engagement Events	589	570	580	594
No Shots	11	30	8	6

(*Only 98 of the 100 Trials For HAMR-2 were completed for the 6 Submarine study.)

Table 16. Scenario BRAVO Basic Statistics - 2 RED Submarines.

Measure (N=200)	P-3	HAMR-1	HAMR-2	HAMR-3
Median Time to first Shot (minutes)	303	461	81	81
Engagement Events	198	195	198	200
No Shots	2	5	2	0

Table 17. Scenario BRAVO Basic Statistics - 1 RED Submarines.

Measure (N=248)	P-3	HAMR-1	HAMR-2	HAMR-3
Median Time to first Shot (minutes)	181	517	80	80
Engagement Events	240	239	242	245
No Shots	8	9	6	3

The HAMR-2 and HAMR-3 configurations which employ P-3's as the weapons delivery platform have a lower "Time to First Shot" than the armed ASW platforms (Figure 21). This can be explained by the nature of target prosecution utilized in the scenario. For each of the armed platforms, only one target will be engaged at a time, that is, targets are engaged in a serial fashion. The HAMR-2 and HAMR-3 platforms are free from the burden of tracking a target to be engaged, they can continue to search the area for additional targets in parallel with the engagement of the first target. Upon the destruction of the first target, the weapons platform that was called to engage the first target can be re-directed to engage a second target immediately. Whereas the P-3 and HAMR-1 platforms would have to search or re-acquire the second target, the HAMR-2 and HAMR-3 platforms can simply direct the responding the weapons platform to the second target post-engagement.

The results for scenario Bravo reveal much about the performance of the various platforms in an engagement scenario, however further analysis is required to fully understand the value of the engagement measure.

Further graphs of the Scenario BRAVO data set show not only a non-normal sample distribution but an extremely high variance as well. Table 18 displays descriptive statistics for the P-3 run of the BRAVO scenario.

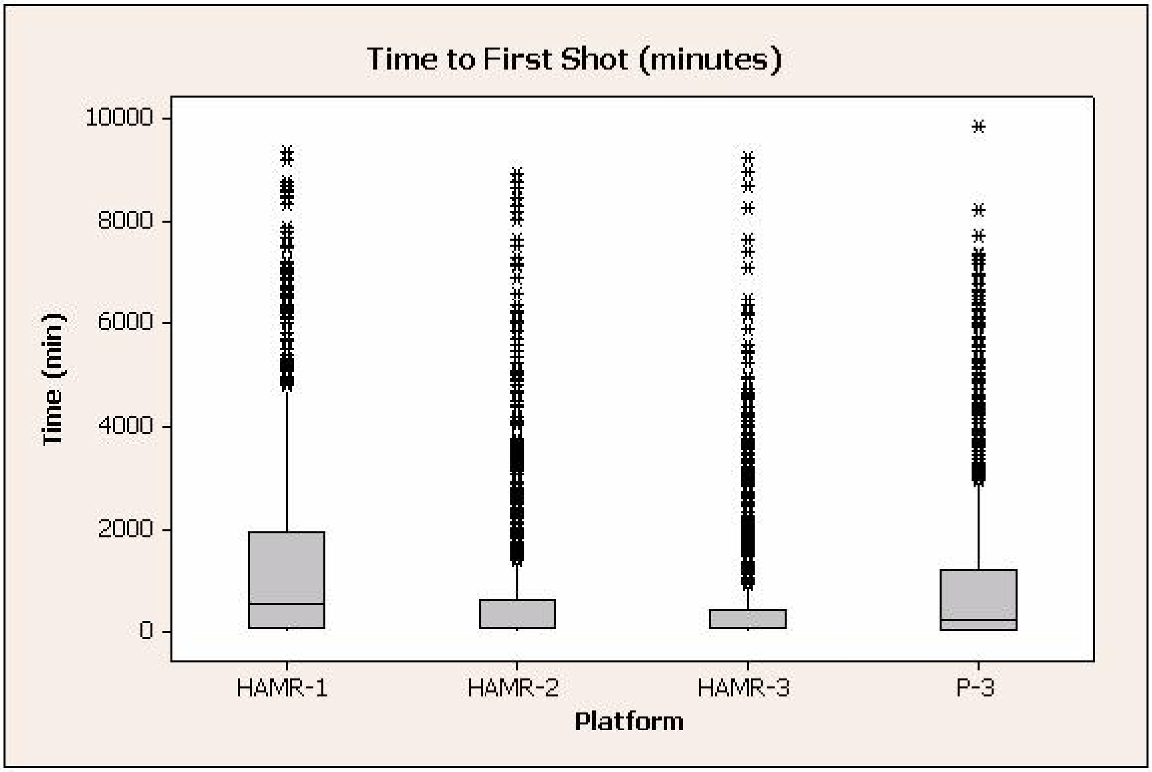


Figure 21. Scenario Bravo Median “Time to First Shot.”

Table 18. Scenario BRAVO Basic Statistics.

Measure (N=1048)	P-3	HAMR-1	HAMR-2	HAMR-3
Median Time to first Shot (minutes)	214	51	80	80
Engagement Events	1027	1004	1020	1039
No Shots	21	44	16	9

The measurement system utilized in scenario Bravo should be examined for further improvement. A suggestion for this would be to set criteria for minimum AOU to begin the engagement interval clock. The extreme values for the 4th quartile distributions can be attributed to the measurements used in the BRAVO scenario. The time measurement begins when a RED submarine is first detected, not at the start of an engagement sequence. It is conceivable that a first detection could occur at hour zero at

the beginning of the scenario. That same submarine could then exit the search region and not be detected again for several days or possibly never seen again for the duration of the scenario (as occurred with "No Shots" in Table 17 scenario BRAVO results, which assume no shot opportunity existed for that detection).

h) *Scenario Charlie*

Scenario CHARLIE occurs over a larger geographical region in the Pacific Ocean east of Japan. The mission objective is to track and trail a RED FORCE submarine contact from Atsugi, Japan to Guam. This scenario was analyzed by spreadsheet computations using Microsoft Excel. The RED FORCE submarine is on transit from Atsugi, Japan to Guam. The BLUE FORCE HAMR or P-3 squadrons are based in Atsugi, Japan. The HAMR and P-3 squadrons always take off and return to Atsugi Air Base in Japan. The input parameters and assumptions in Table 19 were utilized.

Table 19. Scenario CHARLIE Input Parameters.

Parameter	HAMR-1 TORPS	HAMR-2 ARRAY	HAMR-3 BUOYS	P-3
Speed	**75 NM/hr**	**75 NM/hr**	**75 NM/hr**	**328 NM/hr**
Persistence (max flight time)	**168 hrs**	**168 hrs**	**336 hrs**	**14 hrs**
Speed of RED SUB	**5 NM/hr**	**5 NM/hr**	**5 NM/hr**	**5 NM/hr**
Distance from Atsugi, Japan to Guam	**1341 NM**	**1341 NM**	**1341 NM**	**1341 NM**

The following is the derivation of the main equation used in the spreadsheet analysis. It determines the distance the RED submarine will travel in the maximum flight time that the aircraft being analyzed is assumed to have. As the submarine gets farther away from the start, the P-3 or HAMR will need to travel farther out to the submarine and have less time on station tracking the submarine.

- *T1* is the total time the aircraft takes to get to the submarine
- *T2* is the total time the aircraft is tracking submarine

- *T3* is the total time the aircraft takes to get back to base
- *D1* is the total distance the aircraft needs to travel to get to the submarine
- *D2* is the total distance the submarine will travel while the aircraft is tracking it on that sortie
- *D3* is the total distance the aircraft needs to travel back to base
- *S1* is the speed of the aircraft traveling to get to the submarine
- *S2* is the speed of the submarine, constant 5 NM/hr
- *S3* is the speed of the aircraft traveling back to base

In this case the equation was calculated for a P-3, the maximum flight time being 14 hours and the speed of the P-3 being 328 NM/hr. For the alternate HAMRs the appropriate maximum flight time and speed were substituted.

$$T1 + T2 + T3 = Maxflighttime = 14hours$$

$$\frac{D1}{S1} + \frac{D2}{S2} + \frac{D3}{S3} = 14$$

$$\frac{D1}{328} + \frac{D2}{5} + \frac{D3}{328} = 14$$

$D3 = D1 + D2$ *D3* is always equal to *D1* + *D2*

$$\frac{D1}{328} + \frac{D2}{5} + \frac{D1 + D2}{328} = 14$$

$$\frac{2D1}{328} + \frac{D2}{5} + \frac{D2}{328} = 14$$

$$D2\left[\frac{1}{5} + \frac{1}{328}\right] = 14 - \frac{2D1}{328}$$

$$D2 = \frac{14 - \frac{2D1}{328}}{\frac{1}{20} + \frac{1}{328}}$$ This is the main formula

The results of the spreadsheet analysis are summarized in Table 20 below. The P-3 needed the most number of sorties to track the RED submarine from Atsugi, Japan to Guam, which was a total of 29 sorties. HAMR-1 and 2 configurations came in next with a total of 2 sorties needed, a shorter persistence time of 168 hours as compared

to the HAMR-3. The HAMR-3 configuration needed only 1 sortie to complete the mission as the HAMR-3's maximum flight time exceeded the total transit time of the RED submarine. The main factor that contributed to the difference in sorties needed to complete the mission was the estimated persistence time of the aircraft.

Table 20. Scenario CHARLIE Results Summarized.

Measure	HAMR-1 TORPS	HAMR-2 ARRAY	HAMR-3 BUOYS	P-3
Sorties Needed	2	2	1	29

i) Conclusions

The performance modeling and simulation effort resulted in a greater understanding of the various alternative configurations and their utility in various scenarios. As with any research project, the activity raised more questions than were answered. Foremost, what tactics will maximize the performance of the various configurations? It is suggested that follow-on research be conducted to determine the optimal tactical operation of the proposed alternative HAMR platforms.

2. Risk Analysis Overview

This section covers the methodology, tools, and strategies that were employed to manage the risks of the HAMR mission module at a global level. The objectives that guided our risk analysis are early identification of risks, reduction of impact and/or likelihood of negative consequences, and ensuring adequate attention is given to high-risk items. This risk analysis also provides valuable lessons learned and critical risk information for decision makers prior to milestone decisions. Risk reduction was the primary goal of these risk analysis activities and early identification of risk items is critical. Several risks were identified in the key areas of cost, schedule, and technological capability.

The risk management process for the HAMR mission module is to assess risk, mitigate risk, and reassess. Figure 22 provides a graphical illustration of the integration process and Figure 23 demonstrates its cyclic nature. The process of risk identification

was an iterative process that began with a close examination of the nature of HAMR craft. Risks were examined continuously throughout the SEDP process as new issues arose. Continual communications were conducted via teleconference, phone, and e-mail to discover and clarify possible risks. White paper and test articles also provided definitive risk information. These white papers are typically the product of a thorough analysis of some specific problem or issue.

For in-depth risk analysis, formal tools were employed. These include statistical risk analysis concepts, and methodologies. Risk matrices, cost, reliability models, and a fault tree analysis proved valuable for developing risk mitigation plans. The severity of each risk determined if a mitigation plan was necessary, what kind of mitigation plan was needed and when the plan should be implemented. In some cases of low risk items, a mitigation plan was deemed an unnecessary expenditure of resources. These risk items were monitored closely but not necessarily mitigated.

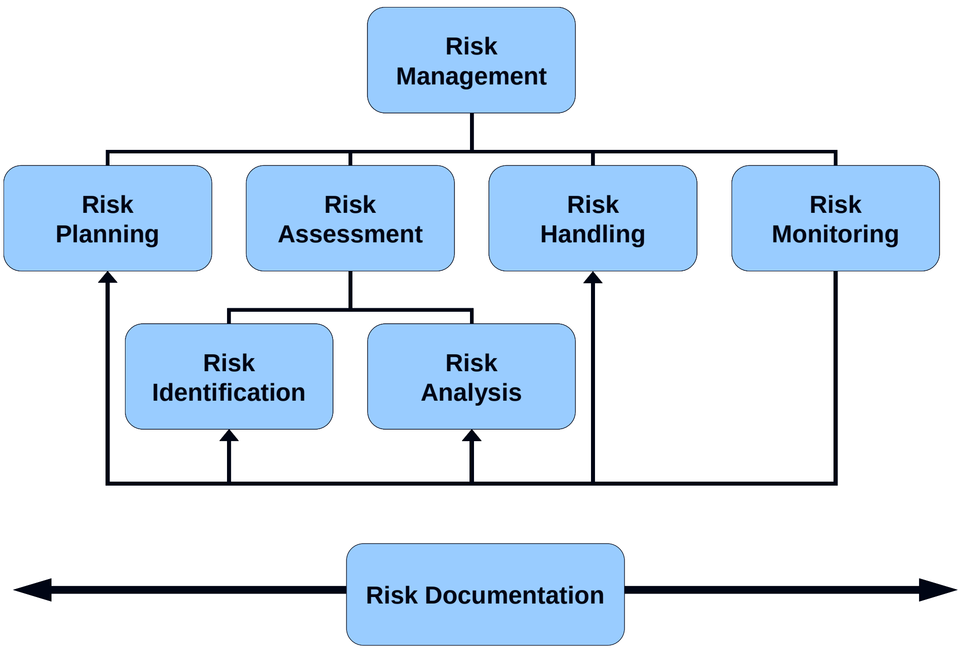


Figure 22. Risk Management Hierarchy.

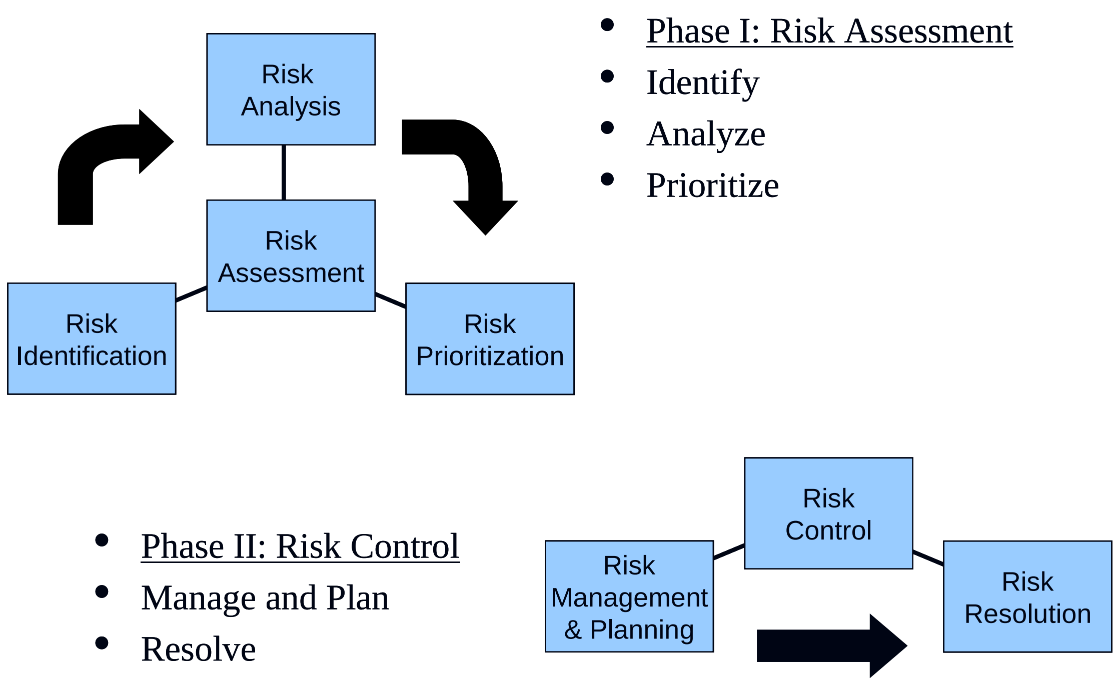


Figure 23. Risk Management Cycle.

a) Risk Prioritization

The HAMR team has instituted an iterative prioritization process. The risk matrix was the key tool in our prioritization process. The probability of occurrence and severity of the consequence of each risk items is illustrated graphically by Figure 24 below. The risk matrix the team chose consisted of five levels of severity and five levels of frequency. Numbers 1 through 5 were used in place of text descriptions. The levels of risk severity used ranged from negligible (1) to catastrophic (5). Risk severity was reached by group consensus after evaluating factors such as initial requirements, availability of information, technological maturity, and external factors. The probabilities of occurrence used were improbable (1), remote (2), occasional (3), probable (4), and frequent (5). The risk prioritization process yielded the following risk.

1. Interoperability
2. Scope Creep
3. Schedule
4. Modeling and Simulation
5. Accuracy of Alternatives
6. System Integration
7. Classification of Information

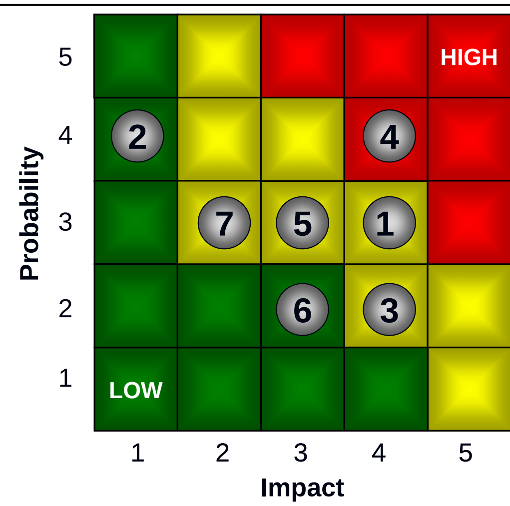


Figure 24. Risk Matrix.

Best and worst case scenarios were evaluated based on potential impacts to the capability, cost, and schedule of HAMR program. A predetermined risk mitigation and management plan was developed for most of the risk items. The process for risk mitigation is also iterative to allow for flexibility to deal with emergent risks. These risk management practices implemented by the project team have made the inherent risk of the integration more manageable.

b) Technical Risk

Technical risk is always a risk factor in any system. This technical risk is defined different ways but is generally characterized by technological maturity. The HAMR ASW mission module has unique technical risks due to the numerous systems aboard. The first step to mitigating the technical risk is to set project boundaries so there are few technological changes to the HAMR that effect the payload module. Secondly, the payload itself is made up of existing ASW systems. Using proven technologies has greatly reduced the likelihood of failures and unexpected risk.

In many cases the ASW systems that are being incorporated into the HAMR mission module have not been grouped together on a single platform. It is not known how all these sensors and systems will interoperate. Until they are all together on a single platform there is an inability to predict possible interferences between the systems. Interoperability and integration risk are undoubtedly one of the most difficult risks to mitigate. There is no precedence for this variety of systems on a platform of this type. Nevertheless, the HAMR team has verified system estimates with SMEs and continues to research possible interoperability and integration problems. The integration risk has been reduced by following models of existing integrated ASW systems. The question remains whether these systems can be integrated without incurring excessive costs.

System integration and interoperability were determined to risk items for the system specific reasons such as:

- Will the submarine systems talk to TIS in a controlled and universal way? The integration with the tactical support systems is a risk that can be resolved with software interfaces. The software interfaces can provide the critical links that are needed to maintain situational awareness among a myriad of sensors suites.
- There is no known precedence of using a towed array on an air platform. Typical air platforms like the P-3 require too much speed to maintain their lift. Too much speed would severely damage a towed array. A helicopter on the other hand could travel at a slower speed but would have to be specifically designed to handle the weight and signal processors of the towed array. This

would render the helicopter useless for any other purpose. Although there is no precedence of using the towed array on an air platform, the HAMR is not the typical air platform. It can handle the weight, signal processors, and speed requirements of towed arrays. Therefore, it is theorized that the HAMR could successfully deploy a towed array.

- There is no precedence for deploying dipping sonar on an Airship. Can the team maintain the steady position required by the dipping sonar? Given the large surface area of the HAMR it is unknown how much deviation would be caused by specific wind forces. The ability of the HAMR to quickly counter unexpected wind forces with its steering mechanisms is unknown. However, the team does have data from a smaller demonstrator model. The team can use this data as a basis and scale it accordingly to the dimensions of the much larger proposed demonstrator.

To mitigate the technical risks above, continued research is being conducted to fully understand the technical complexity of these integrated systems.

c) Modeling and Simulation

Accurately estimating cost, reliability, and performance of the many systems the team intends to model may prove to be difficult. Typically, each ASW system would have a team of dedicated professionals to accurately log and track costs and reliability issues for that system. The HAMR team attempted to acquire this information for over 20 ASW systems. It is likely that our modeling and simulations fail to capture all of this data. Some data may be unknown or unavailable due to security classifications. This is especially true of data such as the maximum operational ranges of sensors. The difficulties of accurately modeling are resolved with increased manning, increased communications with subject matter experts, establishing a policy to deal with classified information, and using "best effort" estimations in place of unavailable data.

d) Scope Creep

Another common risk among acquisition programs is the tendency for scope creep, meaning that requirements may change and even increase in number. Scope creep was noted as a risk early on in the process in order to deliver a reliable and

manageable system. Scope creep was managed using tools such as stakeholders' questionnaires, which help to solidify requirements. Project scope and boundaries were agreed to by stakeholders early, and the requirements were locked in after a designated period.

e) Schedule Risk

Schedule risk is present in every program and the HAMR mission module is no exception. The HAMR group is paying special attention to this particular risk item to avoid schedule overruns, as the project is not focused on systems development, but rather the conceptual design of a system.

f) Accuracy of Alternatives

The capabilities of a suite of sensors may not operate as advertised. Likewise a conglomerate of systems may not achieve their intended result. It is important to consider the possibility of inaccurate assessment of systems' capabilities. This concern can be partially addressed in the modeling and simulation risk area, as well as sensitivity analysis regarding important assumptions with respect to specific alternative system capabilities.

g) Risk Calculations

To perform risk calculations a number was estimated for each of the risks described previously. This risk factor was created to represent the risk items' impact and effects. It is used to calculate the overall risk factor of the alternative under analysis. Risk items are categorized into technical and non-technical risks. Technical risks such as system integration and interoperability vary greatly between alternatives. The risk factor of a risk item is essentially the probability index multiplied by an impact factor of the specified risk. The probability index ranges from 1 to 5 and are enumerated (as mentioned earlier) as improbable (1), remote (2), occasional (3), probable (4), and frequent (5). Each of the probability indicesand impacts were estimated for the risk categories for each alternative. The risk factor product is totaled for all risk items and averaged to yield the overall risk of the alternative. The result is plotted on a risk matrix to compare all alternatives against one another. This process was repeated for each of the alternatives. The results of this analysis are illustrated in Tables 21 – 23.

Table 21. Alternative 1 Risk Scoring.

	Probability	Impact	Product
Interoperability	3	5	15
System Integration	3	5	15
Modeling and Simulation	3	4	12
Accuracy of Alternatives	4	4	16
		Technical Total	58
Scope Creep	2	4	8
Schedule	3	4	12
Classification of Information	3	3	9
		Common Total	29

Alternative 1 Total	**87**
Average	12.42857
Whole number	**12**

Table 22. Alternative 2 Risk Scoring.

	Probability	Impact	Product
Interoperability	5	5	25
System Integration	5	5	25
Modeling and Simulation	5	4	20
Accuracy of Alternatives	4	4	16
		Technical Total	86
Scope Creep	5	4	20
Schedule	4	4	16
Classification of Information	5	3	15
		Common Total	51

Alternative 2 Total	**137**
Average	19.57143
Whole number	**20**

Table 23. Alternative 3 Risk Scoring.

	Probability	Impact	Product
Interoperability	1	5	5
System Integration	2	5	10
Modeling and Simulation	2	4	8
Accuracy of Alternatives	1	4	4
		Technical Total	27
Scope Creep	1	4	4
Schedule	2	4	8
Classification of Information	2	3	6
		Common Total	18

Alternative 3 Total	**45**
Average	6.428571
Whole number	**6**

The results of the risk analysis are plotted in comparative risk matrix in Figure 25 below.

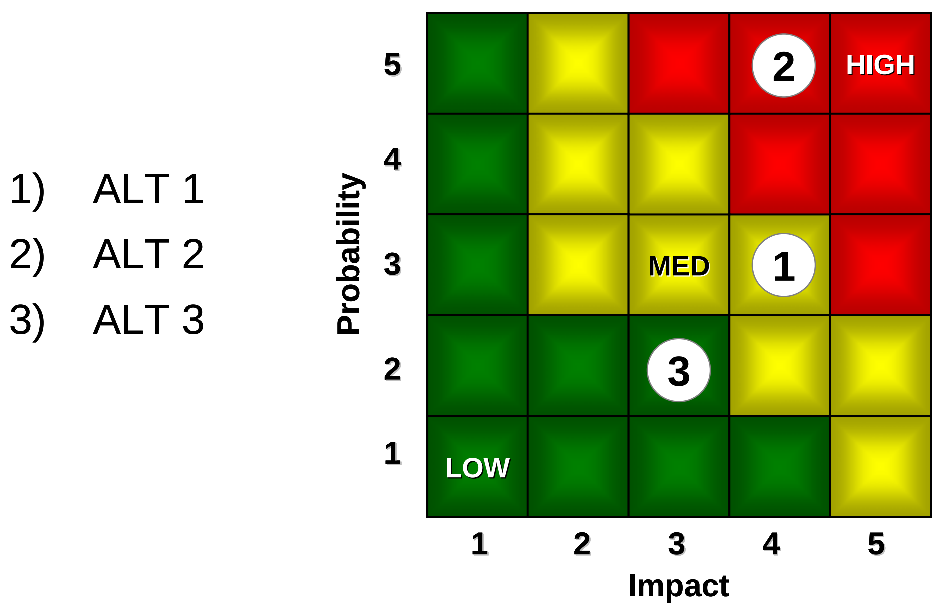


Figure 25. Comparative Risk Matrix for Alternatives.

3. Logistics Analysis

The OPNAV Instruction 4000.85 on the Navy Logistics System provides guidance for the fielding of Navy logistics. The instruction recommends Navy logistics system should be comprised of three elements: acquisition logistics, in-service support, and operational logistics.

a) Acquisition Logistics

The HAMR ASW process, by design, first assessed capabilities from existing, or fielded Navy systems and programs of record. To fill remaining gaps in technology or capability, the process then assessed other commercial off-the-self (COTS) or yet un-fielded technology. Current Navy, or DOD fielded technology offers an obvious acquisition advantage by leveraging the existing logistics categories, including acquisition, currently in place and previously funded. This strategy also includes utilization of the current supply system (Naval Inventory Control Point, NAVICP), on-board sparing, and existing intermediate and depot maintenance which are in both organic and private sectors. New technology will be procured using the acquisition process.

b) In Service Support

Integrated Logistics Support (ILS) will consist of two components: in-service engineering and the associated life cycle support. As previously noted, the support strategy is to leverage existing support infrastructure in use by the system donating each of the selected capabilities. This will significantly reduce the time; logistics support footprint in acquisition cost, engineering resources, and ILS is required to field the HAMR ASW module. In-service engineering also will provide hardware documentation and the fusion of existing manuals into an integrated HAMR technical package describing the HAMR mission module operation, associated systems integration, interaction, and module maintenance requirements. New ILS documents will be created to support new capability alternatives and shall be consistent and comply with Navy standards for technical documents.

c) Operational Logistics

The HAMR ASW module is designed to be a user maintained system. By the nature of the extended mission, users will be qualified to maintain the systems within the operational environment. Per NAVICPINST 4441.15, a consolidated shipboard allowance list (COSAL) will be established to support maintenance and mid-mission repair. Operational logistics beyond user maintenance and repair are to be supported at the intermediate maintenance level currently utilized by the fleet in support of the existing ASW enterprise. This process will take advantage of the existing fleet sparing (COSAL).

4. Integration

As each alternative is procured, installation and integration of the subsystems will begin. The cost for integrating each of the systems onto the overall platform is dictated by the amount of labor required to install each subsystem. The integration cost estimates have been provided by SMEs and include the amount of labor required, the number of workers needed, their salary, and the number of man hours for each task.

5. Logistics Support and Supply Chain

As previously stated, the logistics support is provided by current programs of record where applicable. On-site logistics support for technology unique to the HAMR module will be provided by the original equipment manufacturer (OEM) under service level agreement, performance based logistics contract, or the equipment provider for maintenance or repair. Sparing for on-ship deployment (COSAL) and ongoing mission requirements are to be provided by the supply system. Funding for the supply chain repairable and associated logistics process will be from mission operations funding (OPTAR), which is a standard fleet practice for these services.

6. Operational (Manpower)

This analysis has estimated training and other operational costs for the ASW operation requirements based on ASW SME assessments. The scope of this project does not include support for items such as manning, lodging, fuel, or operational aspects of the HAMR platform itself. Size and weight of these items are excluded as well.

The HAMR is a complicated system and requires trained war fighters to handle, coordinate, repair, maintain, and make vital tactical decisions in an ASW combat environment. The crew is expected to be much smaller than that of a normal sea-going vessel. SME's estimates indicate a two to four man crew is needed to man the various ASW system alternatives on a shift-by-shift basis. Other supervisory crew members and ground crewing for recovery are not included in the manpower assessment. Funding for the training are accounted for in the LCC estimates which include increases in hourly manpower training costs for the operators.

The unmanned alternative provides a potential to further reduce the manning costs and enhance capability. Elimination of manning will require a reduced number of operators on the ground to support a 24-7 mission capability and provides higher risk hostile mission capability not attainable with a manned platform.

7. Disposal and Demilitarization

The cost analysis and plans to dispose and demilitarize alternatives will be provided several years prior to implementation. The workload to uninstall alternatives and the actual disposal and demilitarization make up the majority of these costs. Additional costs may include declassification of information and the disposal of HAZMAT materials depending on the alternative. Asset reutilization for future use in other systems may provide cost savings. SME input is the basis for disposal and demilitarization cost estimates.

The PM and technical warrant holders (TWHs) for the HAMR program provide oversight of the technical decisions to ensure compliance with overarching disposal requirements and regulations. TWHs support the HAMR PM and addresses alternatives, risks, and trade-offs as appropriate. The TWHs also have the authority to make decisions on technical matters, engineering processes, and practices related to the disposal and demilitarization of alternatives, systems, or tools.

8. Cost Analysis

a) Initial Costs

Each platform provides alternatives that need to be initially purchased from existing programs of record. Costs are derived from either SMEs or published documents found from the respective programs or logistics support agencies. Some costs were obtained by researching the National Item Identification Number (NIIN) and the Naval Inventory Control Point (NAVICP) Asset Visibility System. Initial costs cover the current market costs of each alternative. Procurement of future alternatives to replace that item is done through the acquisition strategy using an incremental, technical refresh process. The initial procurement costs comprise the majority of funding for each platform.

A statistical analysis of future year spending provides a way of determining where and when funding should be applied. Inflation rates have been estimated to establish out year costs, and expected costs are in current year dollars. Overall costs of the ASW module can be reduced by procuring the alternatives as soon as possible and from existing program office assets versus buying new. After the first two years of procurement, funding for the alternatives will decline dramatically as the assets will have been purchased. Spikes in the procurement will come later in the life cycle, when the acquisition of new technology is required.

b) Cost Assumptions

At the direction of NAVAIR sponsors, the HAMR aircraft costs and lifecycles were defined as out of the scope of the ASW module research. All costs are per unit for each HAMR module. The HAMR aircraft has not yet been fielded, thus its procurement, hotel amenities for personnel, and other operational life cycle costs are not yet available for analysis. As a direct result, all cost analysis focused exclusively on the systems within the HAMR ASW mission module.

During modeling, the P-3 is used for comparison or as support for the engagement component of the HAMR ASW mission. Complete P-3 life cycle costs would be valuable to make cost comparisons on LCC or components of the ASW mission, however, researching helped obtain limited data which consists of an hour for

hour cost estimate for the P-3. Additionally, the P-3 is a multi-mission maritime aircraft (MMA) which makes isolating its ASW specific mission costs exceptionally complex. The P-3 will be the main hard kill weapon for Alternatives 2 and 3. The calculated cost of P-3 support was derived by a given cost from a P-3 specialist at NAVAIR. SME estimates suggests that there would be eight flights by a P-3 per year, either during wartime or training, at three hours a flight, and at $4,500 per flight in operation costs.[50]

The technical alternatives of the HAMR ASW module focused, by design, on existing mature technology and the strategy adopted an existing means to support the technology. The fielding of technology extracted from existing programs allows utilization and leveraging of the Navy's existing supply and maintenance infrastructures. It also simplifies the components of training and facilitating technical design agents (TDA) roles. Alternately, COTS technology will be supported by the vendor's repair and maintenance processes.

Specific consumables, torpedoes, and sonobuoys, were not included in the cost assessment as they are procured as a result of specific threats and provided to users to carry as a payload. Costs to train personnel to fire or use these devices are included in our analysis as they are actually consumed as in war-shot torpedoes or in water as exercise torpedoes. Sonobuoys which are consumed in any training scenario are included in the life cycle costs as a component of integration and disposal.

c) *Cost Analysis and System Specification Methodology*

The rendered alternatives that were deemed feasible were given a comparative cost benefit analysis to determine how much capability can be provided and at what cost. The cost of each alternative is examined from multiple perspectives. Unit price, estimated integration costs, manpower costs, and many other cost components were used to determine relative alternative costs.

Extensive research was conducted to find the SME of each subsystem. Data collection consisted of a comprehensive and tedious research effort spanning various Navy organizations as well as non-military organizations. The data collected was comprised of any pertinent information that was available and unclassified. Actual costs,

[50] NAVAIR [2008]

SME input, confirmed specs, as well as best effort estimates provided inputs to the HAMR ASW mission module cost models. By finding the SMEs for each subsystem, more accurate estimates of subsystem costs were made. Brainstorming was used to identify which organizations and points of contact (POCs) have oversight of the systems under examination. After each organization was identified, SMEs were sought out by e-mail, phone, personal interviews, and researching efforts on the internet. A list of SMEs for each alternative's systems can be found in Appendix C.

Once the SME was identified, the model name and number for each system became apparent. SMEs provided unit prices, NIINs, system specifications (including size, weight and power), and capability estimates based on current systems of record. The SME was able to either provide documentation for exact costs and system specifications or a rough estimate for the respective system. Unknown variables such as integration costs were given best effort analyses to determine reasonable cost ranges.

Spreadsheet tools were used to capture system data and analyze both mathematically and graphically the relationships and relative costs between systems. Each alternative was thoroughly analyzed from many angles. System cost estimates were categorized by capability to determine in what area the focus of monetary investment will be made for a particular configuration. In order to generate a cost estimate for a single alternative, the cumulative costs of the subsystems were accounted for as accurately as possible. A 20 year life cycle cost (LCC) analysis was performed for each of the three alternatives. A spiral and incremental procurement strategy was employed and included as an acquisition cost category within the LCC analysis. In 2017 and 2022 an incremental technical refresh occurs with a 25% and 30% respective funding increase. The comprehensive approach taken by the cost and logistics team provided a substantial amount of cost information to the decision makers. This important data and analysis enabled the decision makers to make more educated and informed decisions later in the SEDP.

Each alternative is made up of multiple functional objectives. Each functional objective is broken down into subsystems. Reference numbers for each subsystem is shown in Table 24. Graphs which display the individual subsystem costs will associate numbering systems as a reference.

Table 24. Reference Number and System for Each Alternative.

System Reference #	Alternative 1	Alternative 2	Alternative 3
1	Manual Torpedo Preset System – MK437	TIS – SAAS & SPS	TIS - SAAS & SPS
2	TIS - SAAS & SPS	Comms – JTRS (PRC-148)	Comms - JTRS (PRC-148)
3	GCCS-M (USQ-119)	GCCS-M (USQ-119)	GCCS-M (USQ-119)
4	Comms – SATCOM (PRC-117F)	Comms – SATCOM (PRC-117F)	Comms – SATCOM (PRC-117F)
5	Comms - Link 16 - AN/URC-107 (V)	Comms - Link 11 - AN/USQ-125	Comms – Link 11 - AN/USQ-125
6	Comms - Class I Common Data Link (CDL)	Comms - Class I Common Data Link (CDL)	Comms – Link 16 - AN/URC-107 (V)
7	Automated Digital Network System (ADNS)	Automated Digital Network System (ADNS)	Comms – Link 22
8	Sonobuoy Dispenser (Integrated with TIS)	Sonobuoy Dispenser (Integrated with TIS)	Comms – Class I Common Data Link (CDL)
9	Sonobuoy Receiver (ARR 970)	Sonobuoy Receiver (ARR 970)	Automated Digital Network System (ADNS)
10	LW Torpedo – MK54	P-3	Sonobuoy Dispenser (Integrated with TIS)
11	Super Cavitating Munitions – MK258	Towed Array - Thin Line	Sonobuoy Receiver (ARR 970)
12	Smart Depth Bomb (Modified JDAM) MK 82/BLU-111	Towed Array - Handler (OA-9070B)	P-3
13	RAMICS	Synthetic Aperture Sonar	SSQ 53F Passive Sonobuoy
14	SSQ 53F Passive Sonobuoy	Dipping Sonar	SSQ 62E Active Sonobuoy
15	SSQ 62E Active Sonobuoy	SSQ 53F Passive Sonobuoy	SSQ 101 ADAR Sonobuoy
16	SSQ 101 ADAR Sonobuoy	SSQ 62E Active Sonobuoy	SSQ-110 Extended Echo Ranging Sonobuoy
17	SSQ-110 Extended Echo Ranging Sonobuoy	SSQ 101 ADAR Sonobuoy	MAD AN/ASQ 233
18	MAD AN/ASQ 233	SSQ-110 Extended Echo Ranging Sonobuoy	Radar - APY-10 (Surface Search Periscope)
19	Radar - APY-10 (Surface Search Periscope)	MAD AN/ASQ 233	EOIR – HD Telescope Camera (StarFire 3)
20	EOIR - HD Telescope Camera (StarFire 3)	Radar - APY-10 (Surface Search Periscope)	ESM (AN/ALQ-217)
21	ESM (AN/ALQ-217)	EOIR – HD Telescope Camera (StarFire 3)	LIDAR - April Showers
22	LIDAR - April Showers	ESM (AN/ALQ-217)	
23		LIDAR - April Showers	

d) System Costs

Each HAMR alternative will procure systems according to the assessment made in the Alternative Analysis section. A thorough examination of procurement costs is addressed due to its high impact on the total LCC. Procurement is the largest cost contributor in each of the three alternatives and plays a significant role as to when and how much funding should be appropriated. Costs are displayed in four functional objective areas: combat systems, hard kill the weapons, subsurface sensors, and surface sensors. All of the alternatives will hold similar costs in the surface sensor area, while all other functional objectives will have distinct different costs. Procurement costs were totaled and broken down by each system as well as their respective functional objective. A further analysis will show where individual costs occur. Appendix F provides a complete listing of all initial procurement costs for each system including one delivered ASW module.

1. Alternative #1

The total procurement cost of Alternative 1 is nearly $12.8 million. The weapons-rich platform is the only alternative that incurs costs within the hard kill functionality. Most of the hard kill costs come from the RAMICS system, which also includes the MK258 cavitating munitions. The program office for MK54 torpedoes (PMS 404) is funded to provide the fleet with as many assets as needed. At this time, it is not known if the HAMR program will increase the need for torpedoes or reduce it by offsetting other platforms. It is assumed that there will be no additional procurement costs of lightweight torpedoes for the HAMR program beyond the Navy's normal usage.

Costs for Alternative 1 also include funding for combat systems, subsurface sensors, and surface sensors. Combat systems include command and control consoles as well as communication devices. Subsurface sensors are sensors which detect threats under sea level while surface sensors are sensors that detect threats above sea level. Procurement for surface sensors is the largest expense to consider in Alternative 1. Figure 26 shows that the surface sensors account for 63% of the total costs. While the subsurface sensors show a small amount of the procurement cost, combat systems and

hard kill systems split the remaining costs with 19% and 25% respectively going to each functional objective.

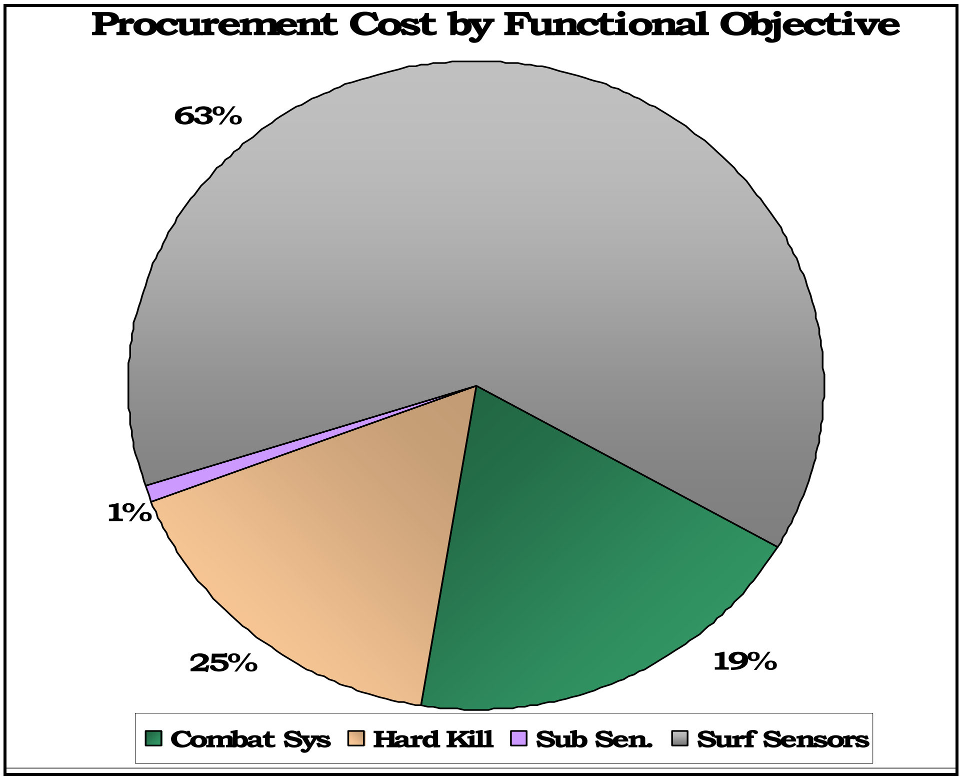


Figure 26. Pie Chart of Alternative 1 Procurement Costs.

Individual system costs provide insight in determining if there are any outliers within a functional objective. A cost breakdown for each system in Alternative 1 is seen in Figure 27. The numbering system for Figure 27 is correlated to the numbering system provided in Table 24 and shows that there are 22 systems to procure. The distribution of combat system costs in Alternative 1 is divided asymmetrically throughout the first nine systems. There are no real outliers for the combat systems, although the sonobuoy receiver is seen to be the largest expense. The cost of the RAMICS system is roughly 14 times larger than all other hard kill costs combined for Alternative 1. However, this does not reflect the procurement efforts needed to ensure the HAMR is properly armed.

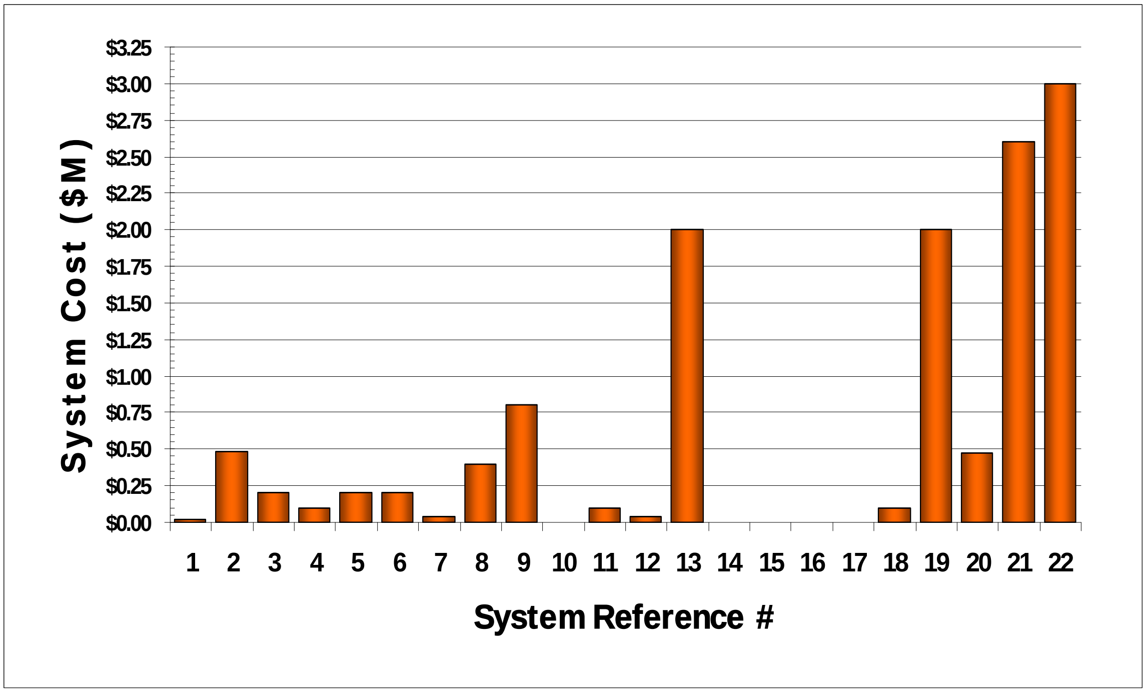


Figure 27. System Procurement Costs for Alternative 1.

Procurement of the subsurface sensors functional objective for Alternative 1, which is made up of sonobuoys and MAD, comes at very little cost. Sonobuoys are similar to torpedoes in the manner that all costs come from a sponsored program office. The program office has already appropriated funding to the development of sonobuoys to ensure the needs of the fleet are met at no additional cost. Procurement of the MAD system is quite small compared to the overall procurement with a cost of $100k.

For all alternatives, the cost to procure surface sensors is identical. All platforms have the same radar, EO/IR, ESM and LIDAR capabilities, thus will all have the same cost. The bulk of the costs come from three of the four systems. The procurement costs of the radar, ESM, and LIDAR systems are expensive, however each system is indispensable. In return, a large amount of funding for procurement costs on each alternative will be devoted to surface sensors. The difference in procurement costs for all of the alternatives will come from the three other functional objectives.

2. Alternative #2

Procurement costs for Alternative 2 consists of only three functional objectives. Figure 28 shows that subsurface sensors and surface sensors make up 87% of the costs while the combat systems cover the remaining costs. This is the only alternative in which the funding for surface sensors is outspent by a different functional objective. Because of the additional subsurface sensors on this platform, the total procurement costs make this alternative the most expensive procurement option.

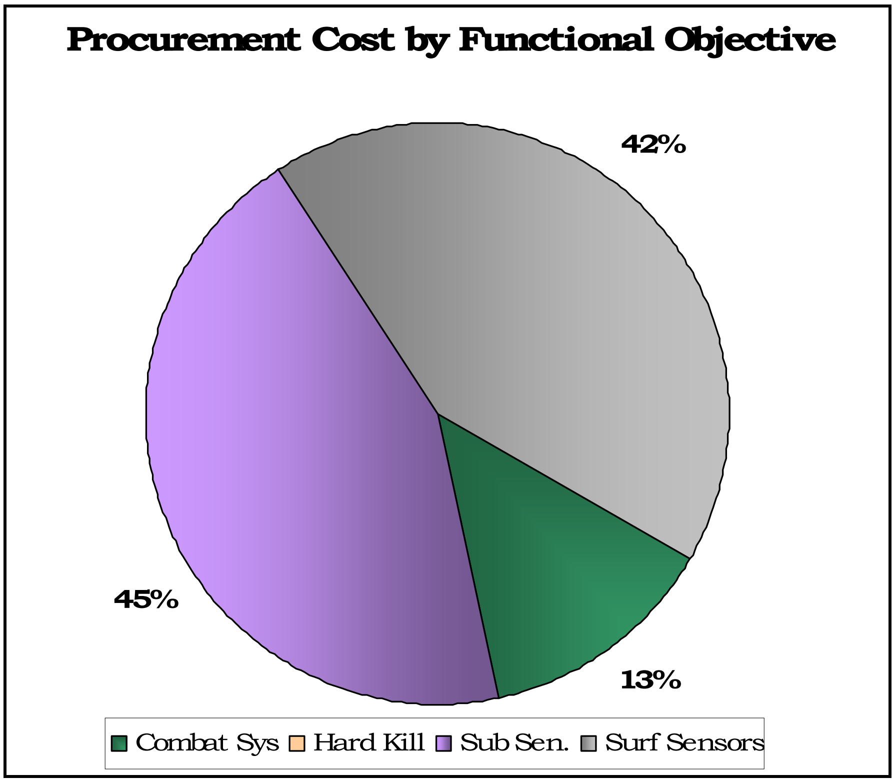


Figure 28. Pie Chart of Alternative 2 Procurement Costs.

The total cost to initially procure Alternative 2 is roughly $19 million. A cost comparison of the different systems in Alternative 2 is displayed in Figure 29. There are no outliers within the combat systems while the subsurface and surface sensors provide multiple outliers within each functional objective. The numbering system for Figure 29 is correlated to the numbering system provided in Table 24 and shows that there are 23 systems to procure. System reference number 10 is P-3 aircraft for and will

not be procured but will be used for hard kill purposes. All sonobuoys (reference numbers 15 through 18) will be procured but at no additional cost.

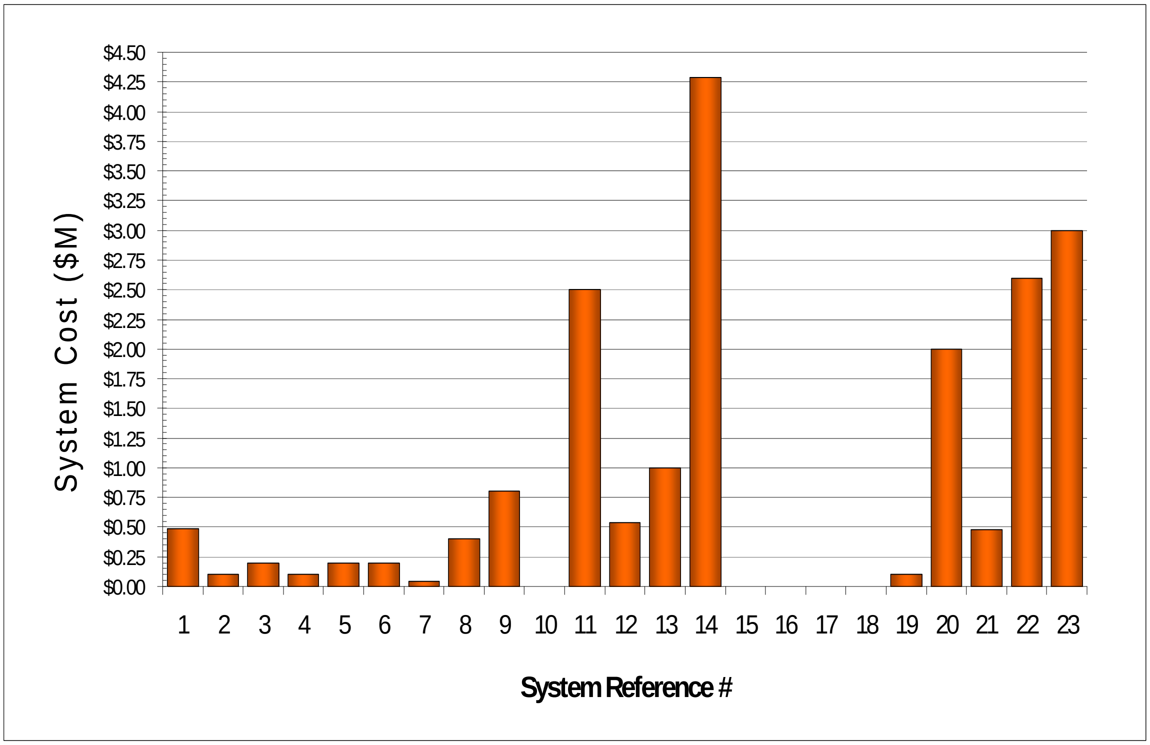


Figure 29. System Procurement Costs for Alternative 2.

Funding is dominated by the three surface sensors and two systems within the subsurface sensor functional objective. The thin line towed array and the towed array handler are separate subsystems that combine to produce one towed array system. The funding for the towed array system comes to just over $3 million. Along with the $4.2 million dipping sonar, the two combine to be the most expensive assets to procure. The dipping sonar is the highest cost item in all the alternatives. Almost 23% of the total cost of Alternative 2 comes from the dipping sonar. This system is comprised of five components: the reel and cable, transducer assembly, reeling machine, reeling machine interface unit, reeling machine control unit, and the sonar transmitter and receiver. These are the only assets in which the costs were researched by using the associated NIIN for each component and then further researched for an exact price on the NAVICP website.

3. Alternative #3

Alternative #3, or the sensor light alternative, is intended to be a reduction of size, weight, and cost. Since Alternative 3 is an unmanned system, hard kill the weapons and enhanced subsurface sensors are not fitted for this system, which will reflect in a reduction in costs. The total procurement cost of Alternative 3 is $11.1 million. Additional communication systems are incorporated, which will slightly increase the combat systems functional objective. Figure 30 reveals that the majority of costs will come from surface sensors.

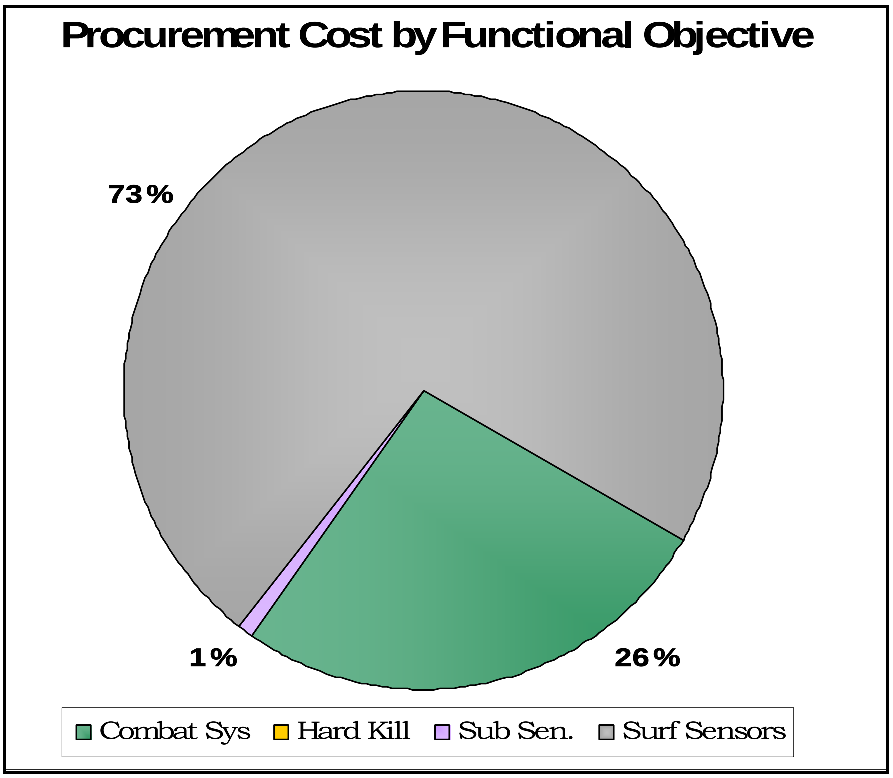


Figure 30. Pie Chart of Alternative 3 Procurement Costs.

One feature that Alternative 3 provides is an increased amount of sonobuoys. Since these are procured from another source of funding, there will not be any additional procurement costs charged to the HAMR program. Figure 31 shows that the only outliers will come by way of the surface sensors.

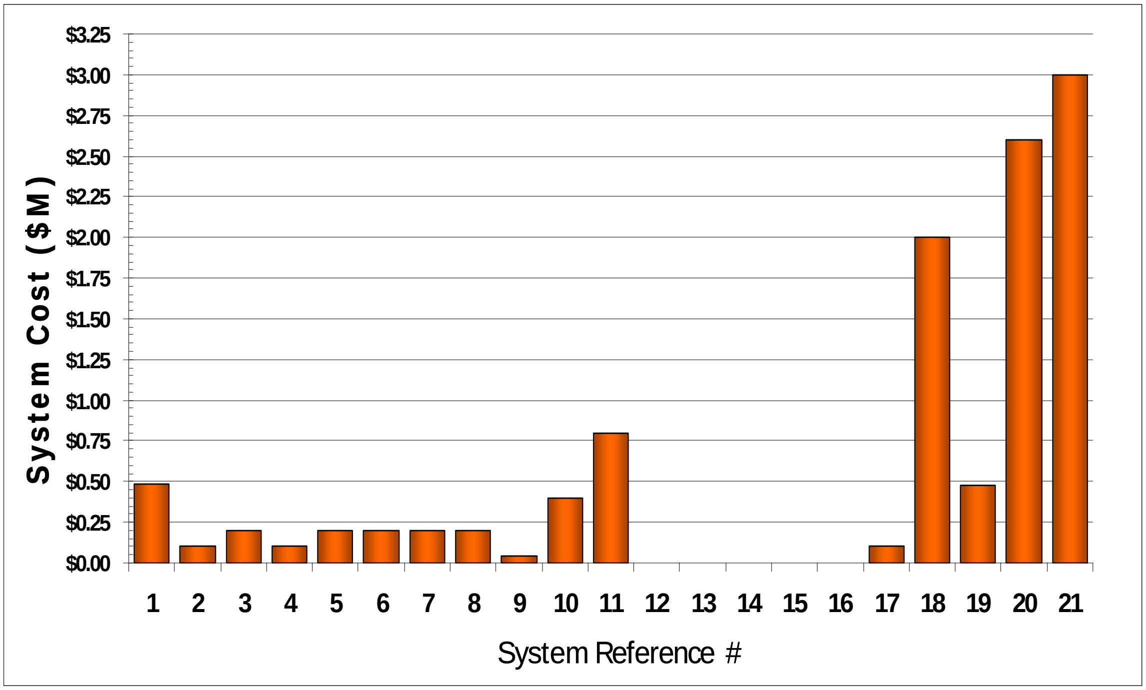


Figure 31. System Procurement Costs for Alternative 3.

e) Life Cycle Costs

Each alternative presents a unique challenge to both acquire and field subsystems throughout the life cycle of the alternative. The total cost of each alternative over a period of time is determined through a LCC analysis. It provides an estimate of how much funding will be required per year to ensure the alternative is fully operational. The entire profile of the LCC is categorized in six different costs: total procurement, integration, logistics, operational, maintenance, and disposal costs. Each of the three alternatives has an individual LCC profile that is examined in further detail.

The length of the alternative's life cycle was a result of several underlying factors. The entire life cycle can be broken down into two phases with the first phase seen as the system acquisition. This depends on how quickly the assets can be procured and integrated, as well as how much funding will be logically appropriate during that time period. The second phase was the actual life cycle of the systems. This includes the logistics, operational, maintenance, and disposal costs associated with fielding the systems. During each year of the life cycle it is assumed that there will be on average eight missions per year, providing 24 hour persistence for a seven day mission. A

detailed analysis of how much is spent in each of these categories for each alternative is found in Appendix D. Each year provides an analysis of the costs appropriated to the respective cost category. After thorough evaluation, it was determined that 20 years would be the appropriate time frame to accomplish the goal to acquiring, fielding, and disposing the systems.

1. Alternative #1

The life cycle of each alternative shows an initial spike in funding with a gradual increase of funding throughout the fielding process. The total LCC of Alternative 1 comes to nearly $50.4 million and is shown in Figure 32. The acquisition phase will take place within the first five years. The largest amount of funding throughout the entire life cycle will come during the second year with nearly $7.5 million appropriated towards 50% of the total initial procurement costs and 20% of the initial installment costs. Accumulation of funding in the following year will lead to the second largest amount with approximately $5.8 million but with 50% of the total integration costs and 20% of the total initial procurement costs.

The fielding phase will begin in year 2012 with just over $1.3 million appropriated to logistics, maintenance, and operational costs. Each year beyond that, costs in each area will gradually increase until 2024 with a total cost just over $1.7 million. The subsequent year will see a decrease in operational cost due to a reduction in training needs. The year 2026 will be the first year that maintenance costs are cut, but it will also be the first year that disposal costs are applied. The final year will consist of disposal and logistics costs. Throughout the entire fielding phase of the life cycle, the logistics costs will increase at a constant rate.

Two additional spikes will come during the technical refresh installments. Nearly $3.1 million in technical refresh costs will be spent during the first year of installment and almost $3.7 million will be spent during the second installment. A 25% and 30% budget of the total initial procurement costs was respectively estimated for the first and second installments.

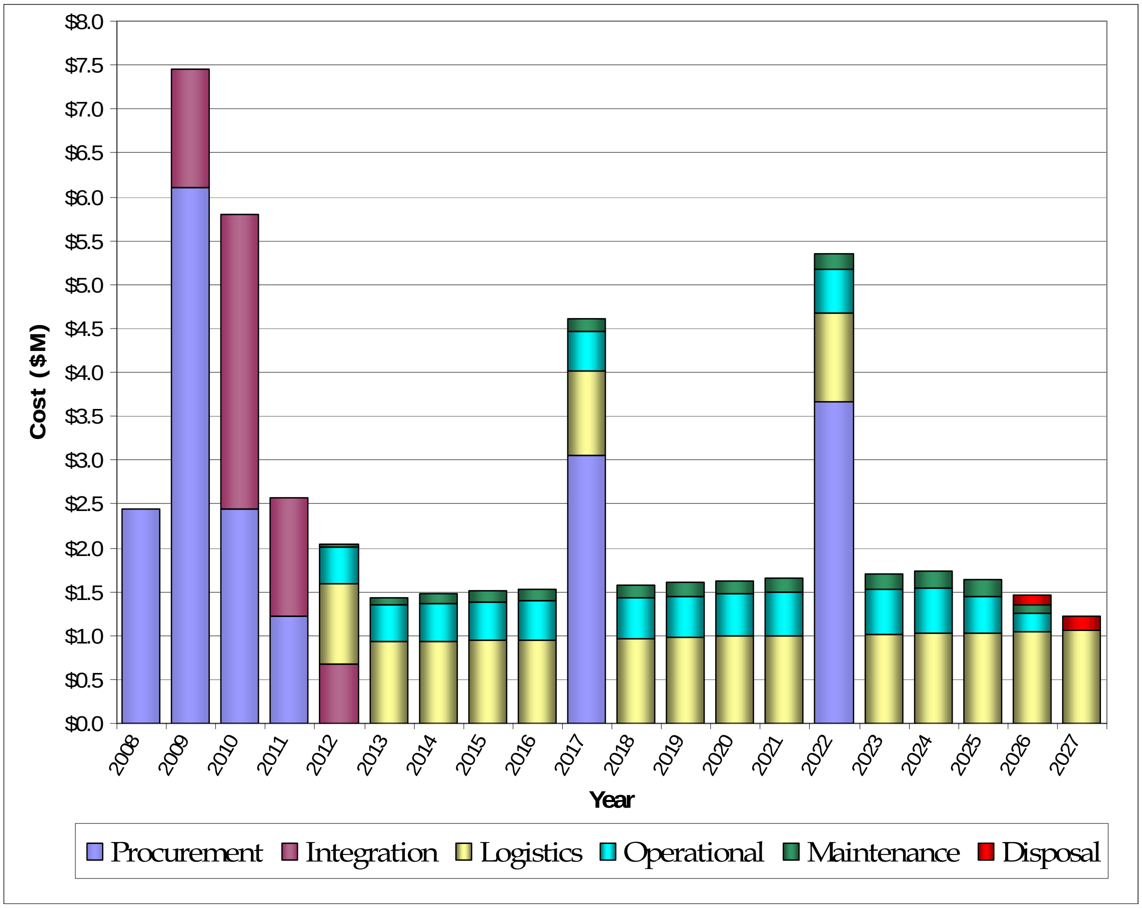


Figure 32. LCC of Alternative 1.

Costs for the acquisition phase and fielding phase in Alternative 1 are quite close even though one phase is five years and the other is 16 years. A distribution of cost categories for LCC is displayed on the left side of Figure 33. The acquisition phase is 51% of the costs while the cost for the fielding phase accounts for the remaining 49%. Initial procurement and the procurement for the technical refresh integration is the largest cost with nearly $19 million in expenses. Logistics makes up almost one third of the total cost and is the other large cost with almost $15.8 million allocated toward this cost category. Funding for the integration and operational costs are very close with roughly $6.7 million going toward each category. Requirements for manning the system will consist of five men for each shift for a total of three shifts. The maintenance and disposal costs are relatively minor compared to the other four costs, but still need to be considered when determining the overall LCC.

The functional objective breakdown for the LCC is slightly different from that of the procurement breakdown. Distribution of the total LCC by the functional objective of Alternative 1 is displayed on the right hand side of Figure 33. Surface sensors remain the largest functional objective with 49% of the total costs. Distribution of the remaining costs will weigh heavily on combat systems where a majority of the funding will come from logistics and operational costs. Just over 60% of the costs for the hard kill functional objectives will come by way of the RAMICS. Costs for subsurface sensors is still dominated by MAD, however the sonobuoys do incur some integration costs.

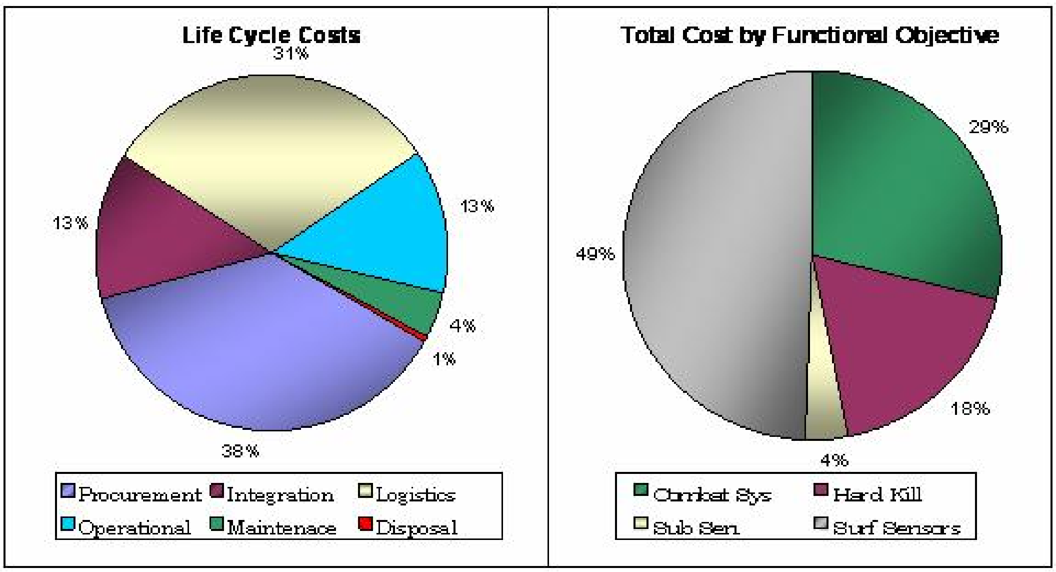


Figure 33. Alternative 1 LCC and Functional Objective Analysis.

Individual system costs reveal what systems supply the largest costs throughout the entire life cycle. The spikes in systems within the LCCs closely follow the spikes in the systems within the Alternative 1 procurement cost analysis. The total costs for each system is seen in Figure 34 with the numbering system associated to Table 24. The only new outlier appears in system 2, which is the TIS system. RAMICS, radar, ESM, and LIDAR continue to dominate the amount of funding for the entire alternative. These five systems range in a magnitude of \$3.8 million to \$8.3 million and account for 63% of the total costs.

Secondary cost categories play a significant role in the LCC. Funding for a particular system may require attention in one cost category and very little in another. All surface sensor systems appear to be heavy in logistic costs as well as TIS and RAMICS. Integration and operational costs are essential to the total, but are not favored to any particular system or functional objective.

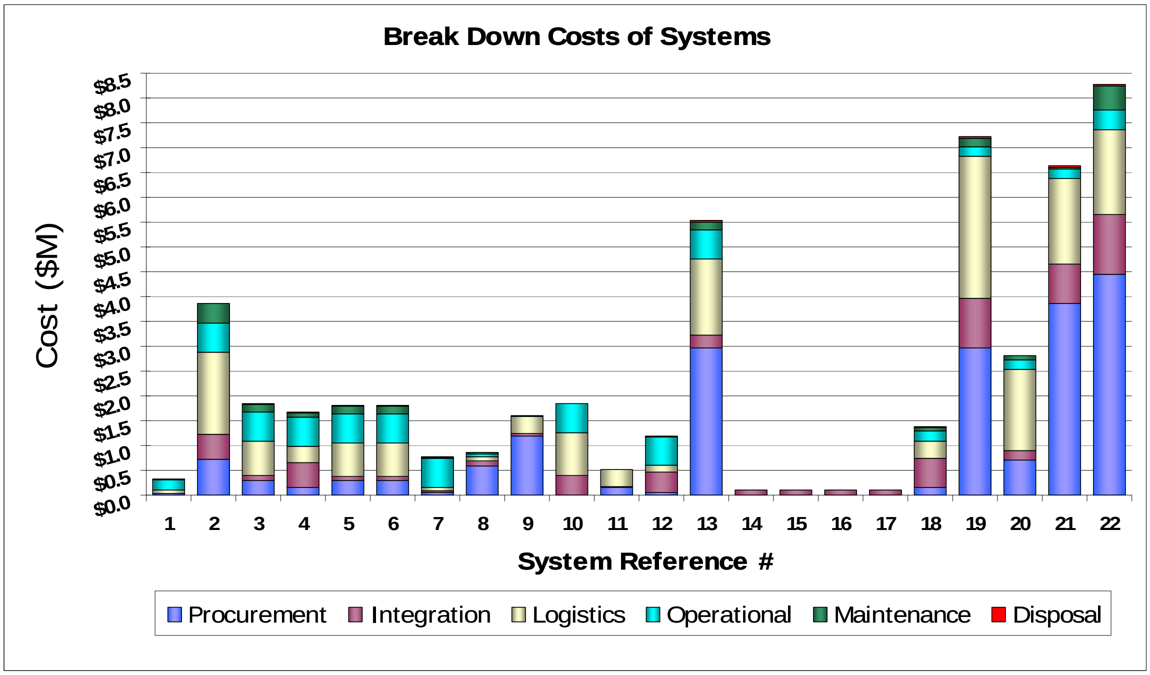


Figure 34. Alternative 1 Total LCC Cost for Each System.

2. Alternative #2

The LCC for Alternative 2 is the largest of the three alternatives with a total cost of just under $69 million. A breakdown of costs for each year is shown in Figure 35. The second and third years of the acquisition phase accounts for the two largest funding years during the life cycle. Allocation of funding in 2009 will come to just over $11.1 million while costs in 2010 will come to just over $8.2 million. The fielding phase will begin in year 2012 with $1.7 million appropriated to logistics, maintenance and operational costs. Each year beyond that, costs in each area will gradually increase until 2024 with a total cost just over $2.1 million. The subsequent year will see a decrease in operational cost due to a reduction in training needs. The year 2026 will be the first year that maintenance costs are cut, but it will also be the first year

that disposal costs are applied. The final year will consist of disposal and logistics costs. Throughout the entire fielding phase of the life cycle, the logistics costs will increase at a constant rate.

Two additional spikes will come during the technical refresh. Nearly $4.7 million in technical refresh costs will be spent during the first year of installment and almost $5.6 million will be spent during the second installment. A 25% and 30% budget of the total initial procurement costs was respectively estimated for the first and second installments.

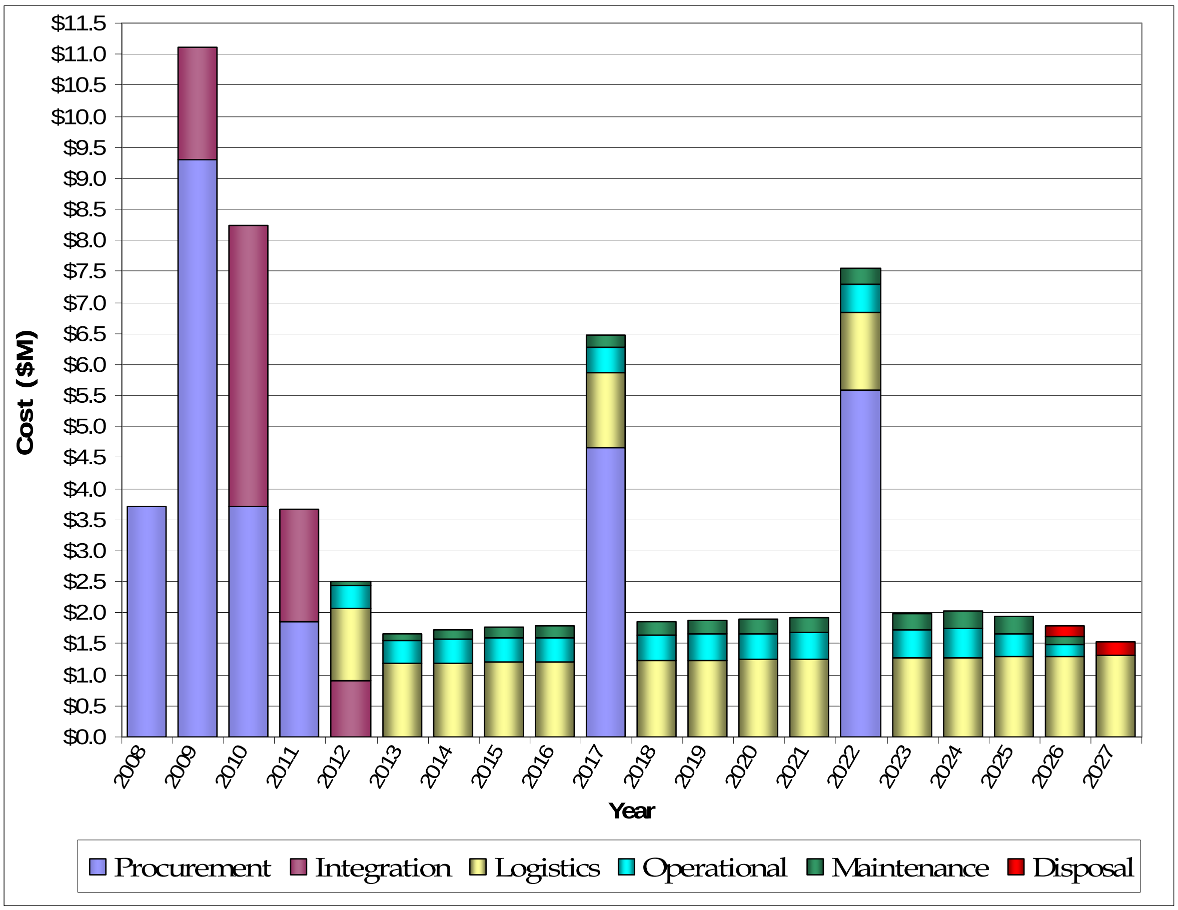


Figure 35. LCC of Alternative 2.

Alternative 2 costs for the acquisition phase are much greater than that of the fielding phase. A distribution of cost categories for LCC is displayed on the left side of Figure 36. The acquisition phase is 55% of the costs while the cost for the fielding

phase accounts for the remaining 45%. Initial procurement and the procurement for the technical refresh integration is the largest cost with nearly $29 million in expenses. Logistics is the second largest cost with almost $20 million allocated towards this cost category. Funding for the integration and operational costs roughly come to $9 million and $5.9 million respectively. Requirements for manning the system will consist of four men for each shift for a total of three shifts. The roles of the two remaining costs are relatively minor, but are still vital to the overall LCC breakdown.

The functional objective breakdown for the LCC is very similar to the procurement breakdown. Distribution of the total LCC by the functional objective of Alternative 2 is displayed on the right hand side of Figure 36. Subsurface sensors remain the largest functional objective with 40% of the total costs. Just over 62% of the costs for subsurface sensors will come by way of the dipping sonar and towed array. Surface sensor costs are closely behind the subsurface sensors in total costs at 36%. Distribution of the remaining costs will weigh heavily on combat systems at 22% where a majority of the funding will come from logistics and operational costs. Hard kill weapon costs from P-3 will make up 3% of the costs.

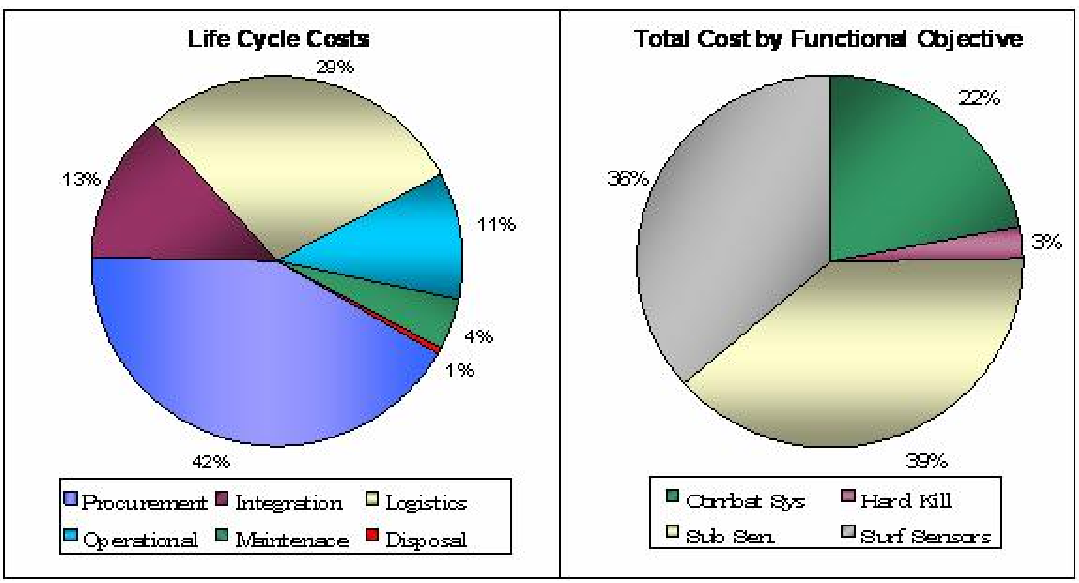


Figure 36. Alternative 2 LCC and Functional Objective Analysis.

Multiple outliers for individual system costs are present within Alternative 2. The total costs for each system is seen in Figure 37 with the numbering system associated to Table 24. While most spikes in systems within the LCCs closely follow the

spikes in the systems within the Alternative 2 procurement cost analysis, there are a few outliers that are unexpected. The TIS system is the only combat system that is an outlier for that functional objective. The towed array, towed array handler, synthetic aperture sonar system, and the dipping sonar are additional outliers that appear in the Alternative 2. Radar, ESM, and LIDAR continue to dominate the amount of funding for the entire alternative. These eight systems range in a magnitude of $3.8 million to $9.7 million and account for 76% of the total costs.

Secondary cost categories play a significant role in the LCC. Funding for a particular system may require attention in one cost category and very little in another. All surface sensors systems and the subsurface outliers appear to be heavy in logistic costs as well as TIS. Integration and operational costs are essential to the total but are not favored to any particular system or functional objective.

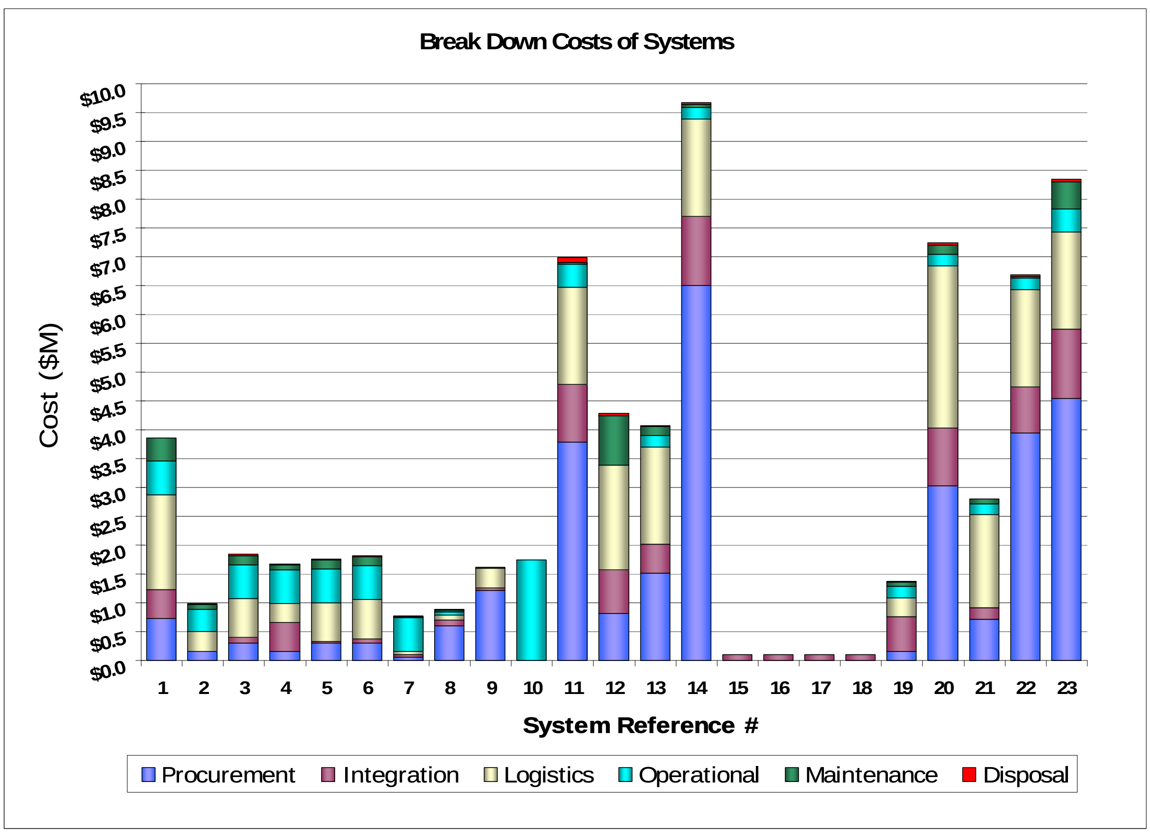


Figure 37. Alternative 2 Total LCC Cost for Each System.

System reference number 10 shows the costs of the P-3 at $1.75 million over the course of 20 years. Both Alternative 2 and 3 provide the same operation costs for the P-3, while no other costs are applied to the hard kill option. However, the P-3 hard kill option in Alternative 3 is system reference number 12.

3. Alternative #3

The LCC for Alternative 3 is the smallest of the three alternatives with a total cost of nearly $44.4 million. A breakdown of costs for each year is shown in Figure 38. The second and third years of the acquisition phase accounts for the two largest funding years during the life cycle. Allocation of funding in 2009 will come to $6.5 million while costs in 2010 will come to $5 million. The fielding phase will begin in year 2012 with $1.2 million appropriated to logistics, maintenance, and operational costs. Each year beyond that, costs in each area will gradually increase until 2024 with a total cost just over $1.5 million. The subsequent year will see a decrease in operational cost due to a reduction in training needs. The year 2026 will be the first year that maintenance costs are cut, but it will also be the first year that disposal costs are applied. The final year will consist of disposal and logistics costs. Throughout the entire fielding phase of the life cycle, the logistics costs will increase at a constant rate.

Two additional spikes will come during the technical refresh installments. Nearly $2.7 million in technical refresh costs will be spent during the first year of installment and $3.2 million will be spent during the second installment. A 25% and 30% budget of the total initial procurement costs was respectively estimated for the first and second installments.

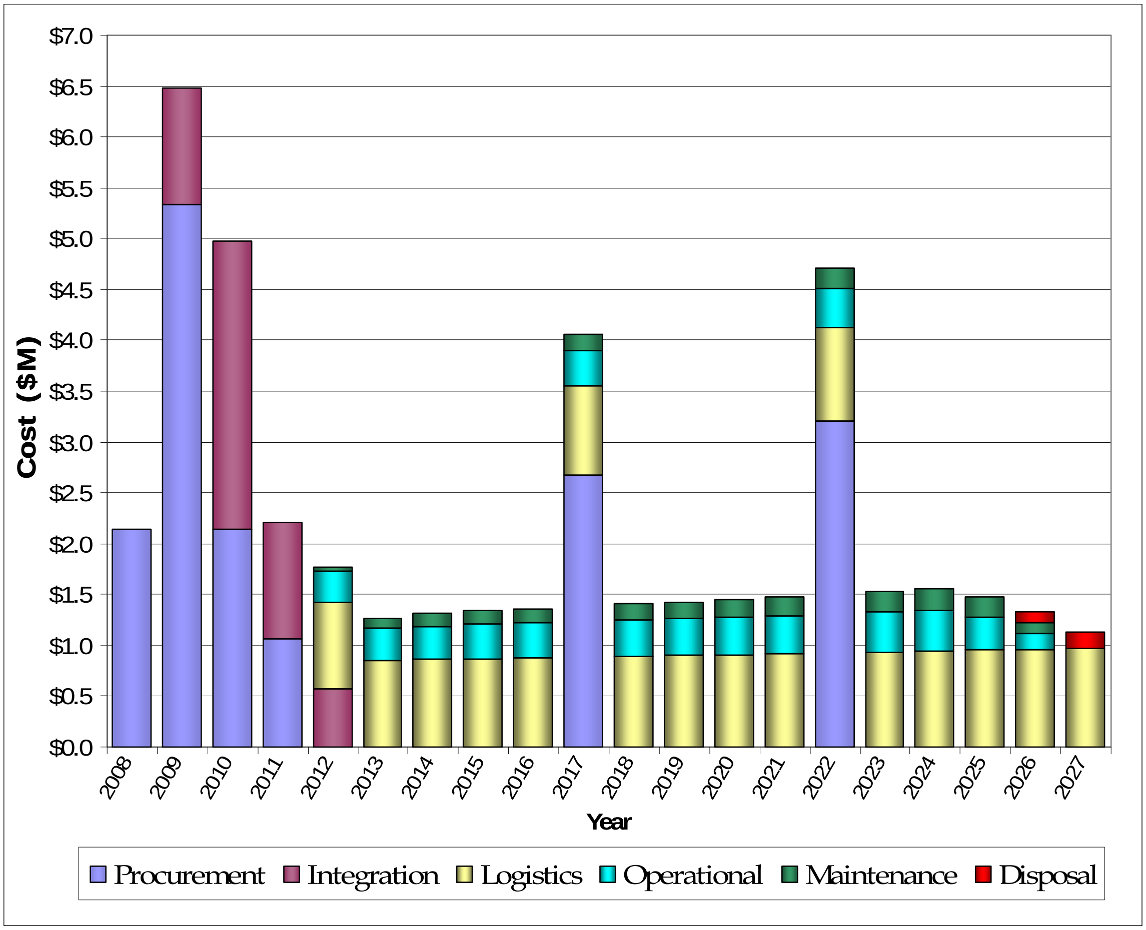


Figure 38. LCC of Alternative 3.

The cost of the acquisition phase of Alternative 3 is slightly greater than the fielding phase. A distribution of cost categories for the LCC is displayed on the left side of Figure 39. The acquisition phase is 50% of the costs, while the cost for the fielding phase accounts for the remaining 50%. Initial procurement and the procurement for the technical refresh integration is the largest cost with nearly $16.6 million in expenses. Logistics is the second largest cost with just over $14.5 million allocated towards this cost category. Integration cost make up for $5.7 million of the total costs and are spread out throughout all functional objectives. Operational costs roughly come to $5.1 million and are somewhat less in comparison to the three other alternatives since Alternative 3 is an unmanned system. Requirements for manning the system will consist of two men for each shift for a total of three shifts. The two remaining costs are relatively minor, however they still play an important role in the overall LCC.

The functional objective breakdown for the LCC is very similar to the Alternative 3 procurement breakdown. Distribution of the total LCC by the functional objective of Alternative 3 is displayed on the right hand side of Figure 39. Surface sensors remain the largest functional objective with 55% of the total costs. Just over 61% of the costs for subsurface sensors will come by way of the dipping sonar and towed array. Distribution of the remaining costs will weigh heavily on combat systems where a majority of the funding will come from logistics and operational costs.

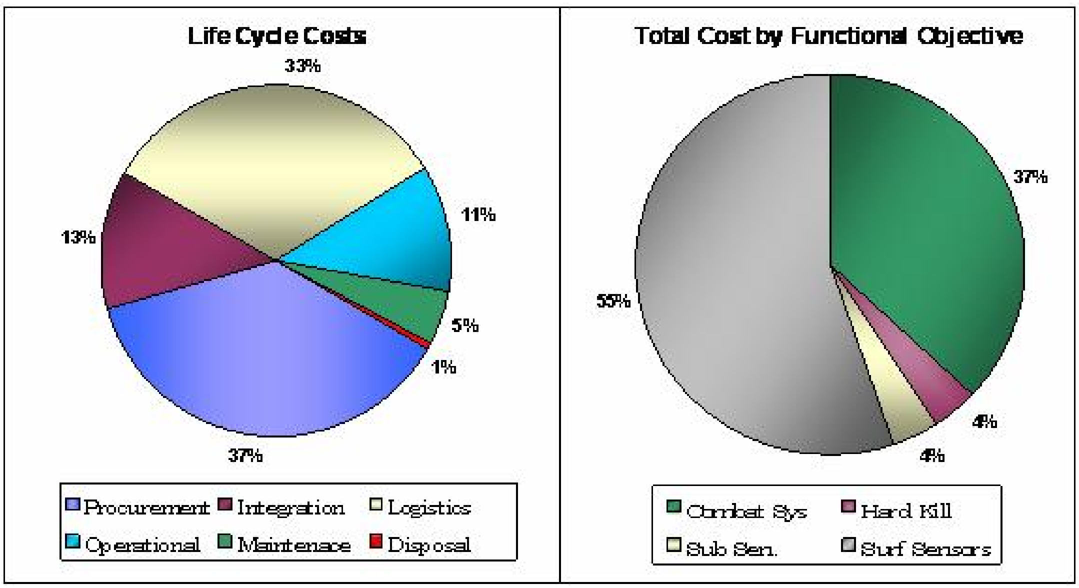


Figure 39. Alternative 3 LCC and Functional Objective Analysis.

Multiple outliers for individual system costs are present within Alternative 3. The total costs for each system is seen in Figure 40 with the numbering system associated to Table 24. While most spikes in systems within the LCCs closely follow the spikes in the systems within the Alternative 3 procurement cost analysis, there is one outlier that is unexpected. The TIS system is an outlier that is not an outlier for within procurement cost analysis. Radar, ESM, and LIDAR continue to dominate the amount of funding for the entire alternative. These four systems range in a magnitude of $3.8 million to $8.1 million and account for 60% of the total costs.

Secondary cost categories play a significant role in the LCC. Funding for a particular system may require attention in one cost category and very little in another.

All surface sensors systems and combat system outliers appear to be heavy in logistic costs. Integration and operational costs are essential to the total but are not favored to any particular system or functional objective.

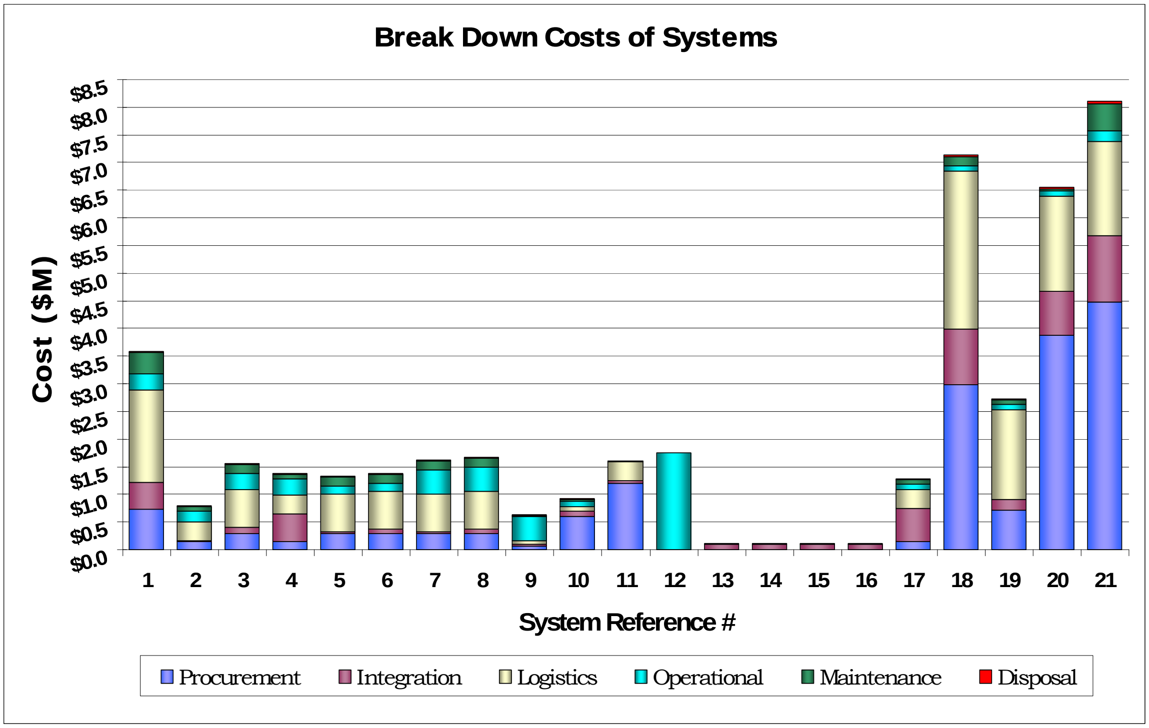


Figure 40. Alternative 3 Total LCC Cost for Each System.

f) Alternative Comparison

Each alternative has unique capabilities and a cost breakdown by functional objective that provides useful information to decision makers. The total procurement expenditures based on capability are summarized in Figure 41.

In all three alternatives a significant and equal investment is made to the surface sensor area. Roughly $8 million dollars is allocated for this purpose for each alternative. This investment is made primarily in sonobuoy technology as they are critical to most ASW activities. Likewise, an equal amount of combat system funding was dedicated to each alternative for the same reasons. These combat systems are also an ASW necessity because they provide situational awareness to the HAMR platform. The combat systems also include the communication capability for transmitting tracks to other platforms. Communication is the primary offensive the weapon for both

Alternatives 2 and 3 as they do not engage the target directly but instead they track coordinates and communicate the information to existing fleet platforms to initiate a hard kill. Alternative 1, however, does allocate approximately $2.1 millions dollars toward hard kill systems such as light weight torpedoes and smart depth bombs.

In Alternatives 1 and 3 a cost reduction is reflected in the total cost since these are considered to be light subsurface sensor platforms. The cost reduction is an effect of program offices having sonobuoys readily available. This is in contrast to the heavy weight subsurface sensor platform, Alternative 2, which requires a large amount of initial funds. A large portion of this funding is allocated for the procurement of the synthetic aperture sonar, dipping sonar, towed array, and the towed array handler. The capability and functional objective cost break down illustrates to decision makers where investments are being made. This information is used later in the SE design process to influence future configurations.

Procurement Cost by Function	Combat Systems	Hard Kill	Subsurface Sensors	Surface Sensors	Total
Alternative 1	$2.45 M	$2.14 M	$100 K	$8.08 M	$12.8 M
Alternative 2	$2.53 M	$ -	$8.43 M	$8.08 M	$19.0 M
Alternative 3	$2.93 M	$ -	$100 K	$8.08 M	$11.1 M

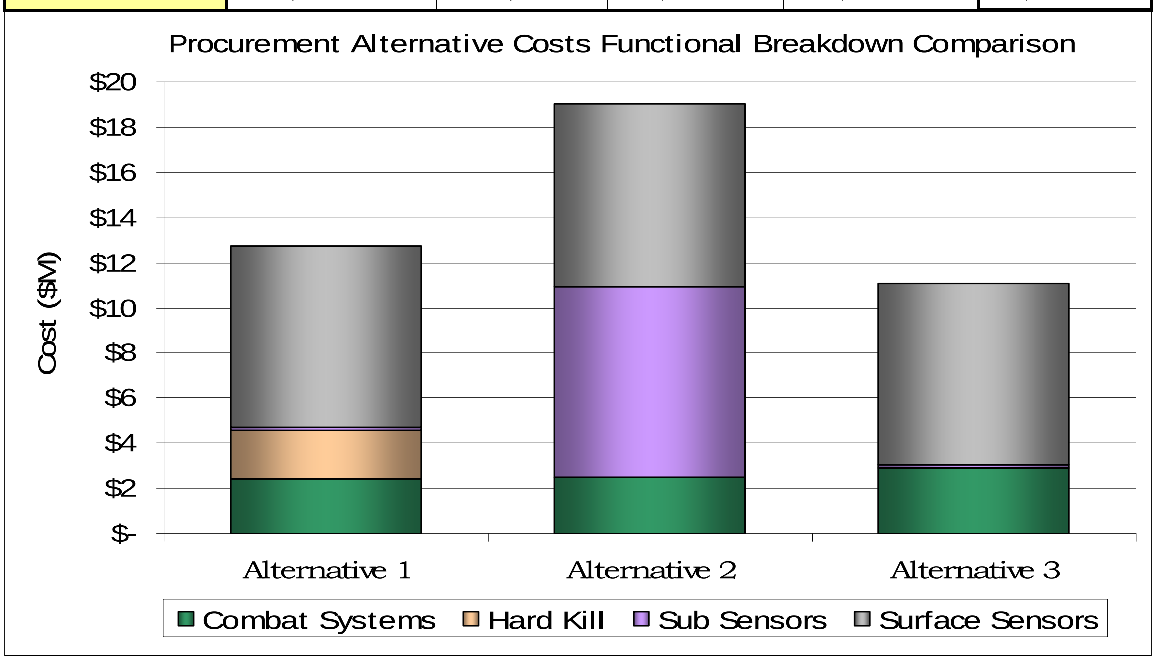


Figure 41. Alternative Match-up of Procurement Costs.

The total LCC for each alternative is quite different. Figure 42 shows the total cost (in millions) for each alternative and is broken down by its functional objective. Since Alternative 3 is the only unmanned system, it is appropriate that it is the least expensive. Alternative 3 does not have extra subsurface sensor nor does it have any hard kill the weapons. This will dramatically reduce the costs compared to the other systems. Alternative 1 is the second most expensive option due to its funding expenses for hard kill the weapons. Additional subsurface sensors make Alternative 2 the most expensive alternative. Because of the extra subsurface sensors, a difference of almost $25 million is applied to Alternative 2.

Surface sensor costs are slightly different due to the incremental technical refresh. More technical refresh funding is applied to the alternative that has a higher procurement cost. A percentage of the alternative's technical refresh expenses will be divided proportionally to each system.

Procurement Cost by Function	Combat Systems	Hard Kill	Subsurface Sensors	Surface Sensors	Total
Alternative 1	$14.6 M	$9.08 M	$1.8 M	$24.9 M	$50.4 M
Alternative 2	$15.2 M	$1.75 M	$26.8 M	$25.1 M	$68.8 M
Alternative 3	$16.4 M	$1.75 M	$1.7 M	$24.5 M	$44.4 M

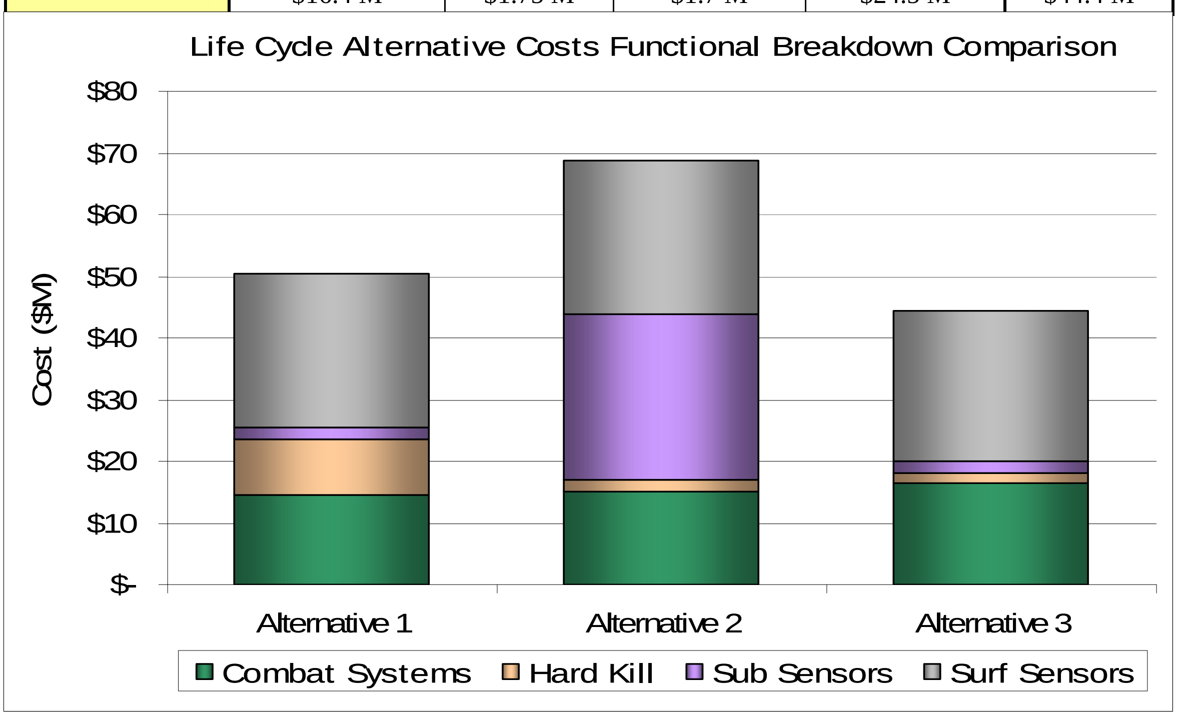


Figure 42. Alternative Match-up of the LCCs.

g) System Specifications

System specifications provide information needed to determine requirements and constraints for modules on each alternative for storage and handling purposes. This will help stakeholders determine which alternative module is suitable for their needs and provide information for future estimates for the physical module. Specifications for each system include the size (in cubic feet), weight (in tons), and power (in kilo watts). SMEs found in the costs analysis section were able to provide some input on specifications for some systems. Research of system documentation was the most widely used method of determining the specifications. Confirmed system specifications as well as best effort estimates provided inputs to the HAMR ASW mission module data tables. SMEs for each system were able to substantiate and supplement system requirements.

Specifications for each of the systems are broken down into total size, weight and power as well as the respective percent consumed or required for each alternative. A table of system specifications for each alternative can be found in Appendix G.

Derivations of the system specifications for each alternative were found in order to analyze differences in functional objectives. Individual system analyses for each alternative provide data on which systems are outliers.

1. Alternative #1

Alternative 1 includes various ASW components which utilizes systems that consume a large amount of space and power and requires a module can hold a substantial amount of weight. Systems that use at least 10% or more of the size, weight and power are considered outliers. The outliers within Alternative 1 include the Tactical Integrated Sensor (TIS) combat system, MK-54 light weight torpedo, various sonobuoys, surface search radar, RAMICS, and smart depth bombs. Alternative 1 will require a total power of approximately nine thousand watts (9 kW) in order to operate the systems.

Figure 49 provides a comparison of the various systems which make up Alternative 1. The system specifications seen in Figure 43 are associated with the numbering reference system in Table 24. The weapons and sonobuoys contribute greatly to the total weight Alternative 1 with 28.9 tons, while it occupies 795 cubic feet and

consumes 8.9 kW of power. The ASW module also contains two smart bombs, item number 12, each weighing in excess of 2,000 pounds, and the sonobuoy load of 1,080 units, item number 14, accounts for 26% of the weight and 33% of the cubic footage. The RAMICS gun munitions, item 11, comprise of 15% of the total weight.

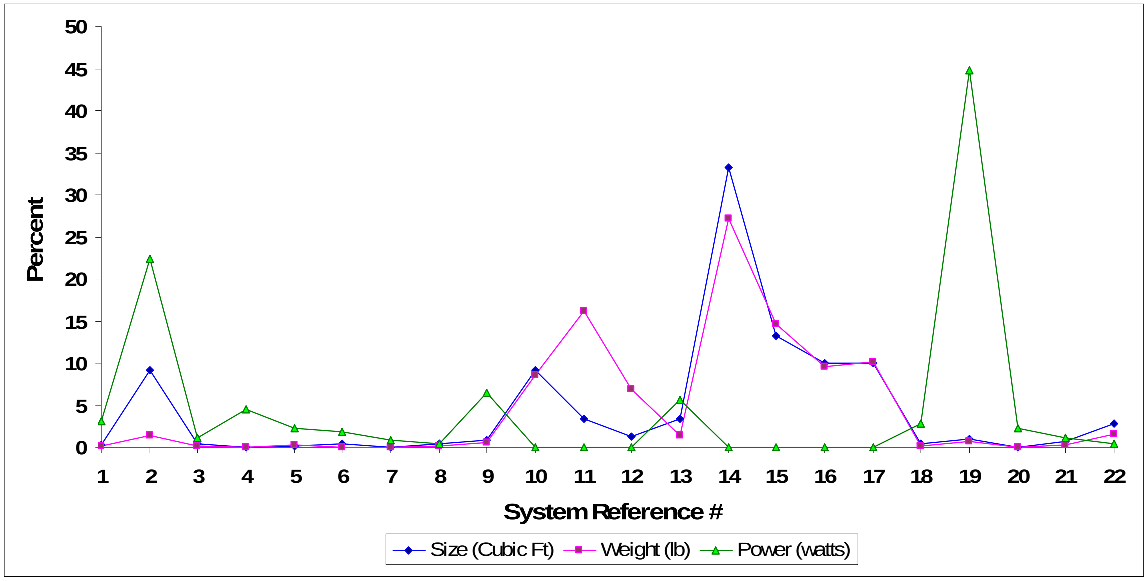


Figure 43. Alternative 1 Specifications of Each System.

The functional objectives represented in Alternative 1 are combat systems, hard kill the weapons, subsurface sensors, and surface sensors. Figure 44 displays the three specifications for the respective functional objectives. Subsurface sensors provide the most size and weight while combats systems and surface sensors supply the most power.

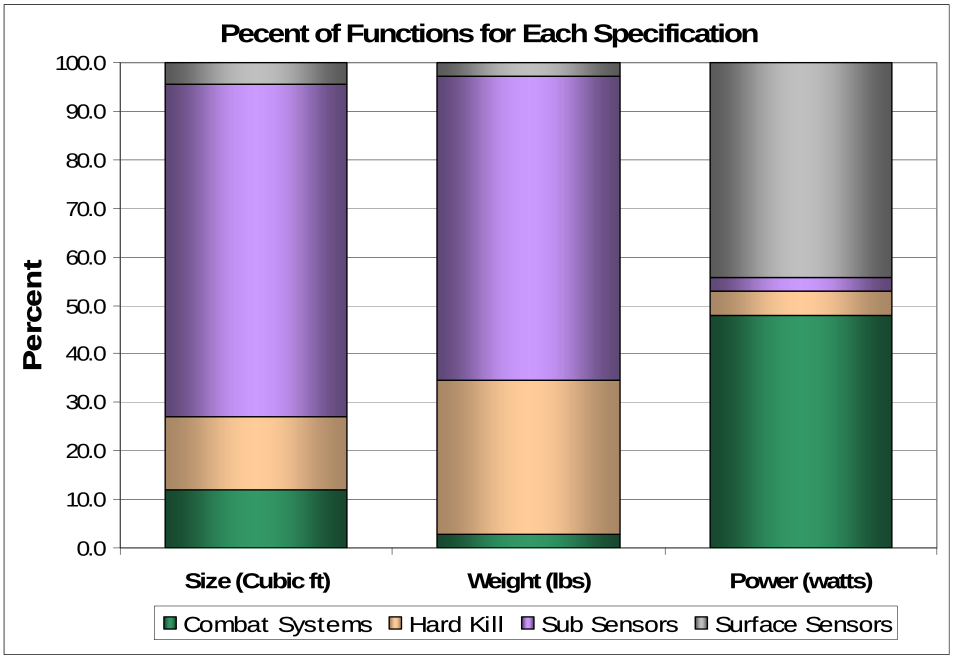


Figure 44. Alternative 1 Distribution of Functional Objectives for Each Specification.

2. Alternative #2

While Alternative 2 reduces ASW capabilities by removing the weapons and adding enhanced additional subsurface sensing provides a different specification outlook. Outliers for this alternative include the TIS system, the towed array, the towed handler, sonobuoys, SAS, and radar. Figure 45 displays the break down of individual system and their respective specification.

Subsurface sensors continue to be a major contributor to the overall weight of roughly 26.9 tons, occupying 763 cubic feet, and consuming 9.4 kW of power. This is due to the vast amount of size and weight required for sonobuoys. The thin line towed array, item 12, and its retracting handler represent 20% of the total with the sonobuoy load of 1,080 units, item 15, at 28% of the total. Power requirements for the alternative are slightly over 9.4 kW and continue to be divided mainly between the TIS combat system, item 1, and the surface search radar, item 20.

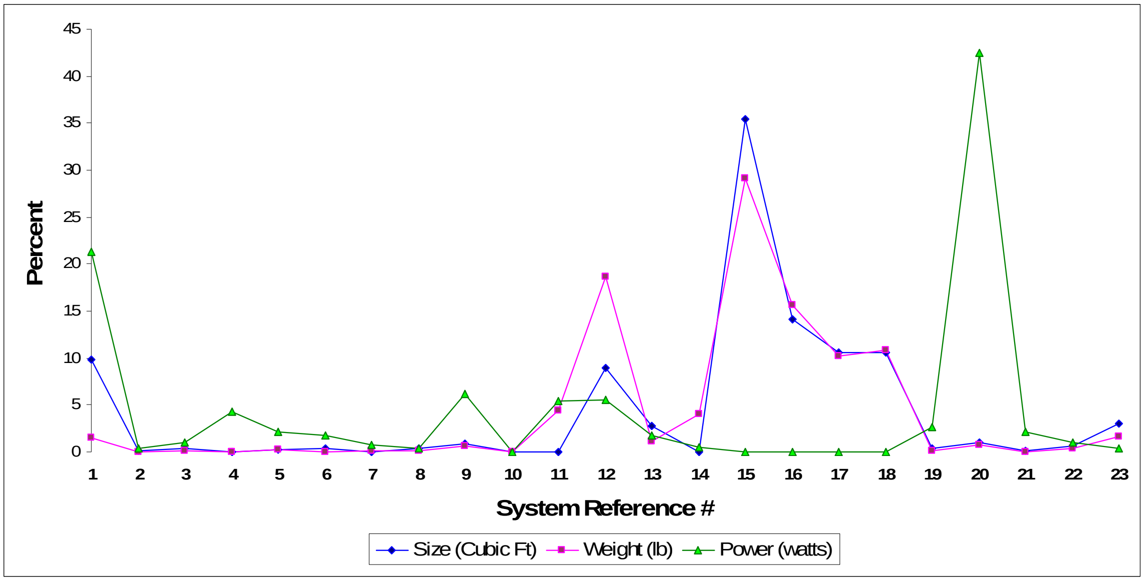


Figure 45. Alternative 2 Specifications of Each System.

Specifications for Alternative 2 are reduced to three functional objectives. Subsurface sensors take up nearly 83% of the total size and nearly 95% of the total weight. Figure 46 displays the three specifications and their respective functional objectives. Combat systems and surface sensors do not play a large role in size and weight constrains, however they do require 43% and 42% of the power respectively.

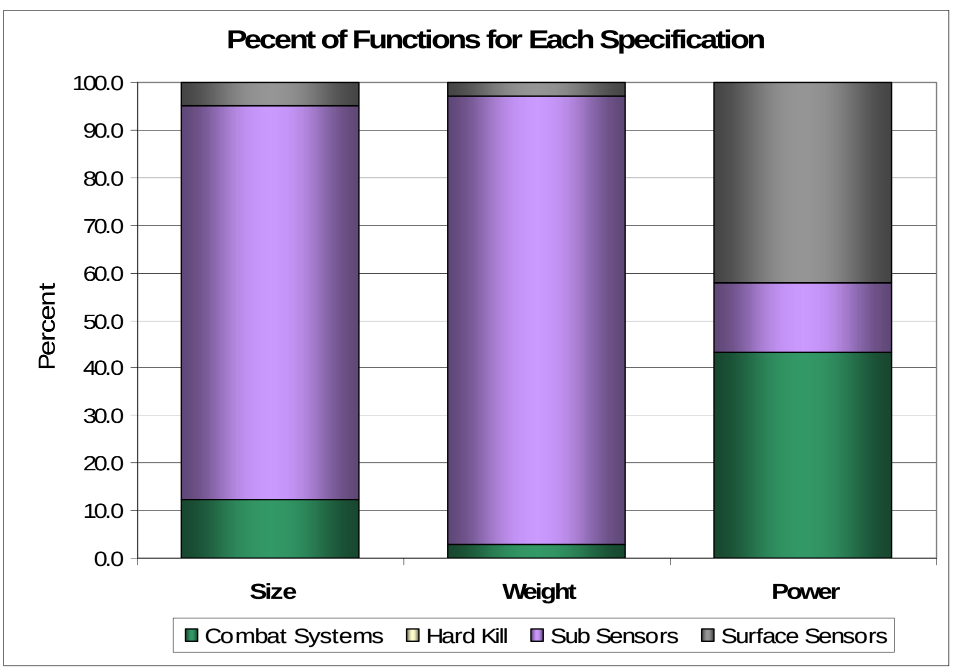


Figure 46. Alternative 2 Distribution of Functional Objectives for Each Specification.

3. Alternative #3

Alternative 3 is also a non-prosecutorial capability ASW Module with subsurface sensors limited to 2,160 sonobuoys. Outliers for this alternative include the TIS system, the towed array, the towed handler, sonobuoys, SAS, and radar. Figure 47 provides a comparison of the various systems that make up Alternative 3. The system specifications seen in Figure 47 are associated with the numbering reference system in Table 24.

The total weight, size, and power specifications are the smallest of the three alternatives. The total weight of Alternative 3 comes to 19.4 tons total with a size of 675 cubic feet and consuming 8.6 kW of power. The extensive sonobuoy load, item 13, represents 43% of the total weight and 42% of the space requirements for the platform. The power requirements for all systems come to 8.6 kW with the TIS Combat System, item 1, consuming 22% of the power and the surface search radar at 43%. Alternative 3 affords both the lowest power consumption and lowest weight of the three alternatives. In addition, Alternative 3 also eliminates manning requirements.

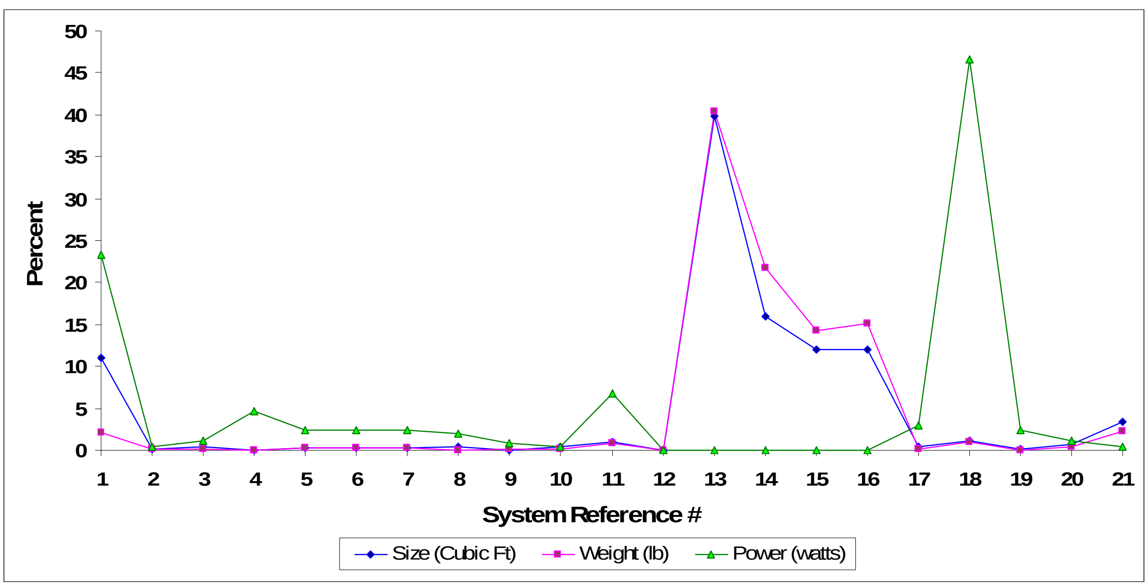


Figure 47. Alternative 3 Specifications of Each System.

Specifications for Alternative 3 are reduced to three functional objectives. Subsurface sensors take up nearly 82% of the total size and nearly 92% of the total

weight. Figure 48 displays the three specifications and their respective functional objectives. Combat systems and surface sensors do not play a large role in size and weight constrains, however they do require 47% and 51% of the power respectively.

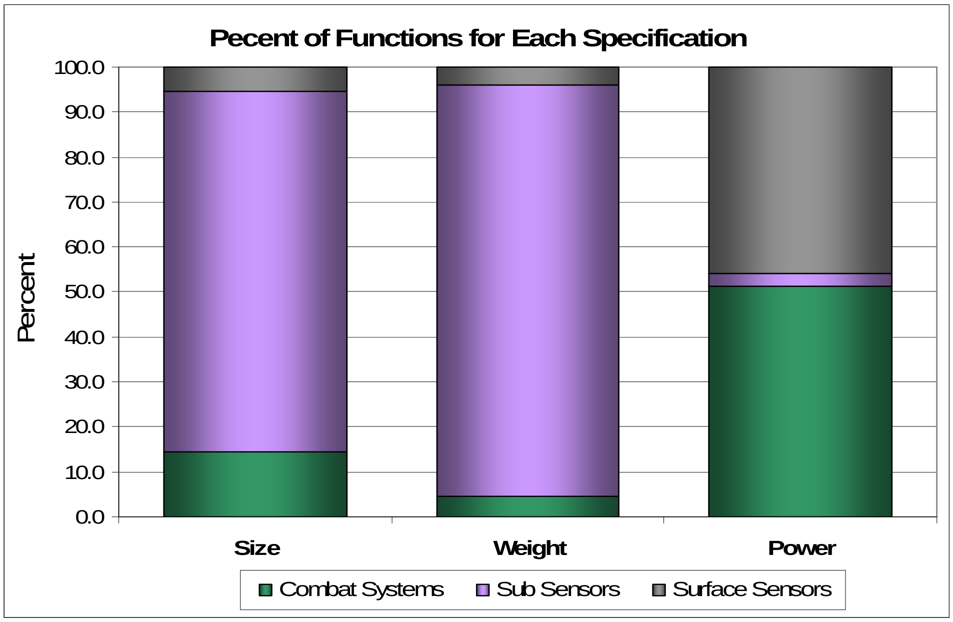


Figure 48. Alternative 3 Distribution of Functional Objectives for Each Specification.

All three alternatives meet weight requirements set by the stakeholders. No constraints were set for the size and power specifications by the stakeholders. Table 25 shows the weight, size, and power specifications of the three alternatives and their differences. When comparing the three system specifications it shows that Alternative 1 is the biggest and heaviest alternative, while Alternative 2 requires the most amount of power and Alternative 3 requires the least amount of size and power, and weights the least.

Table 25. Alternatives 1 – 3 System Specifications.

Total by Specification	Size (ft^3)	Weight (tons)	Power (kW)
Alternative 1	814	28.9	8.9
Alternative 2	763	26.9	9.4
Alternative 3	677	19.4	8.6

h) *Cost-Related Research Recommendations*

Based on the cost analysis, several opportunities for subsequent research should be addressed. Cost savings should be expected in the process of using a HAMR as an ASW platform. Our modeling yielded a 6:1 ratio in P-3 aircraft to HAMR platforms. SMEs have noted that this is likely a conservative estimate with the number being closer to 6:1 ratio.[51] Research on this topic might further justify the use of the HAMR and the ASW module based on total costs.

Additional research on the LCCs of the P-3 and upcoming P-8 may provide a cost justification for the use of the HAMR and the ASW module when actual procurement and actual operating costs of both platforms are accurately known.

[51] Boensel [2008]

IV. DECISION MAKING

A. ALTERNATIVE SCORING

The evaluation of alternatives to determine their overall performance in relation to the objectives established by stakeholders was performed using multi-attribute decision analysis techniques. There are three main components of the multi-attribute decision analysis, value scoring, the raw data matrix containing data generated in the modeling and analysis of alternatives, and the decision matrix. [52]

1. Value Scoring

In the modeling and analysis phase there were three simulation scenarios and an analysis of logistics considerations performed, each of these produced a single performance measure considered valid in the decision analysis. The multi-attribute decision analysis will use the data generated for the following four decision measures and their associated value scores as the basis for the alternative scoring.

Average Total Time of Detection: The data for this measure was derived from Scenario ALPHA. It represents the average time that an enemy submarine was detected while it was within the blue asset area of operation during the simulations. Because of the nature of scenario ALPHA, the measure of total time of detection represents the performance of the various systems in the objective of increasing the probability of detection better than the probability of detection measure given in the value structure. The probability of detection in this scenario is a measure based almost entirely on the performance of sonobuoys rather than the unique capabilities of the alternatives, whereas the total time detected reflects the size of the sonobuoy field the asset is capable of maintaining and to a smaller extent, the persistence of the asset. The value curve for this data, shown in Figure 49, is an s-curve with endpoint values between 0 and 31 hours. The endpoints were selected based on the range of outcomes in the simulation. The s-curve is formed to reflect that the relative value gained per hour of detection time is not equal for all possible outcomes. There is a range of values representing the greatest

[52] Paulo [2006]

increase in value per hour. These values are represented by the linear portion of the curve. .

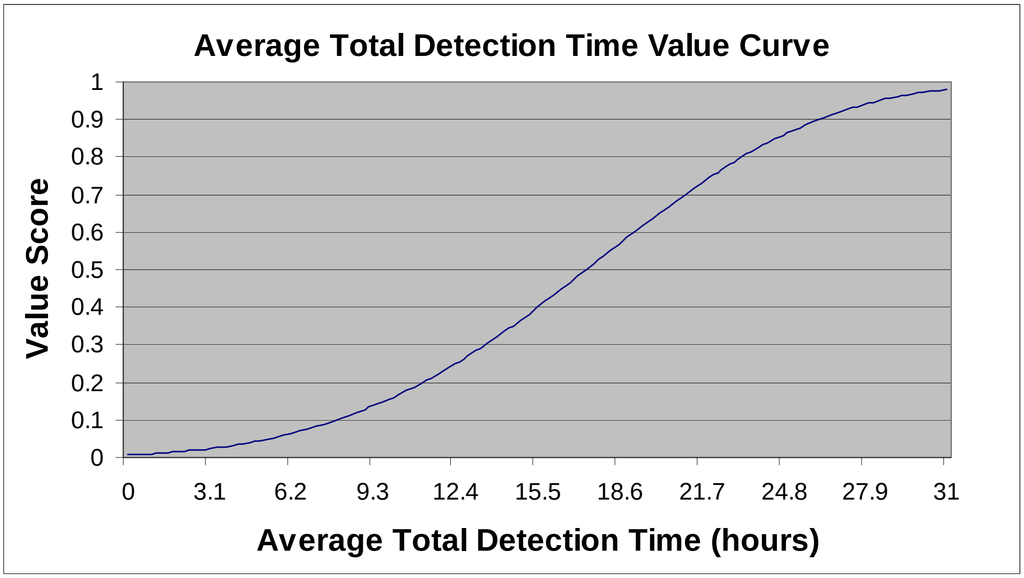


Figure 49. Scenario Alpha Value Curve.

Median Time to Prosecute: The data for this measure was derived from scenario BRAVO. It represents the median time required for a blue force asset to fire a shot measured from the time of first detection during the simulation. The median was used in this case because a number of extremely high special cause outliers skewed the average time to prosecute data. This measure encompasses the time from first detection to classification, percentage of time track maintained, average time from track to firing point procedures, and average time from firing solution to kill measures of the value structure as it was impossible to measure or derive meaningful data for the measures individually. The value curve for this data, shown in Figure 50, is an s-curve with values between 0 and 600. Like time of detection, the endpoints were selected based on the range of outcomes in the simulation. The s-curves were created to reflect that the relative value lost per minute of time spent prosecuting is not considered equal for all possible outcomes. There is a range of values representing the greatest increase in value for each minute not spent prosecuting. These values are represented by the linear portion of the s-curve.

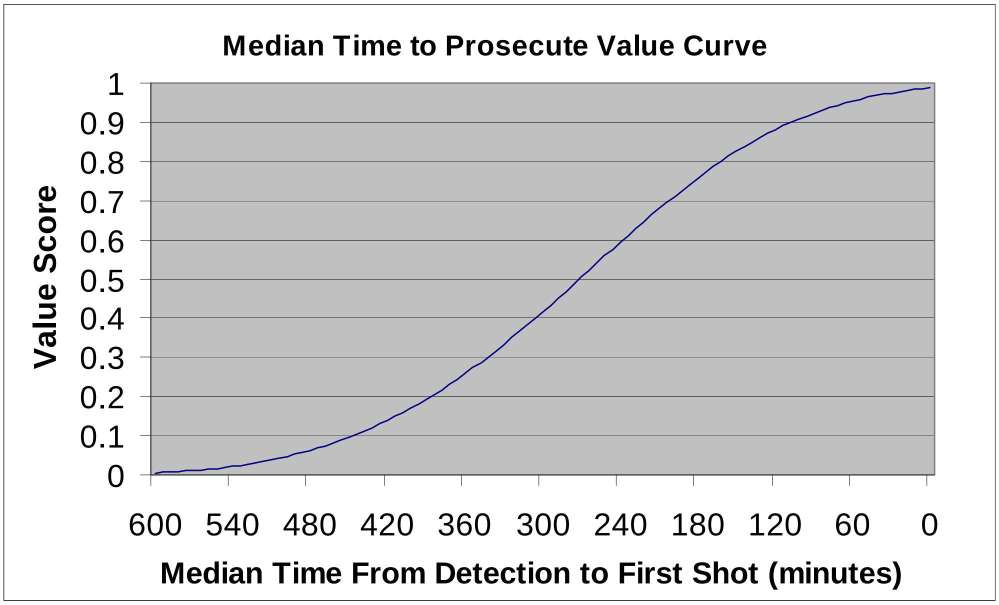


Figure 50. Scenario BRAVO Value Curve.

Total Number of Sorties Required: The data for this measure was derived from the results of scenario CHARLIE. It represents the total number of sorties that were required to be flown to accomplish the mission. This measure corresponds directly to the time on station measure of the value structure. The benefit of using the number of sorties rather than the total time on station is that it better represents the operational performance of the asset and provides a better basis for comparison to the P-3 in this scenario. The value curve for this data, shown in Figure 51, is linear with values between 30 and 1 sortie. The endpoints were selected based on the outcomes of the simulation and the curve reflects a risk neutral approach assigning equal value to each sortie.

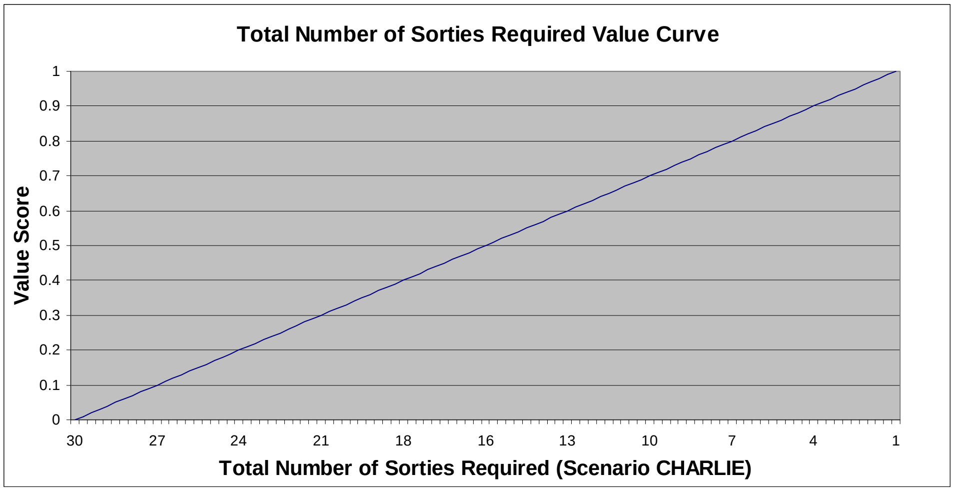


Figure 51. Scenario CHARLIE Value Curve.

ASW Systems Manning per Watch: The estimates for the systems requiring manning was generated in the logistics analysis and was based on the capabilities of the TIS system and known manning requirements for other systems. The value curve for this data, shown in Figure 52, is a curve with values between 0 and 6 individuals. The endpoints were selected based on the preference of stakeholders and the current manning of the P-3 with the curve indicating a "risk prone"[53] approach to increasing value on reduced manning and emphasize the desire of the stakeholders to have an unmanned platform.

[53] Sage [2000:p.403]

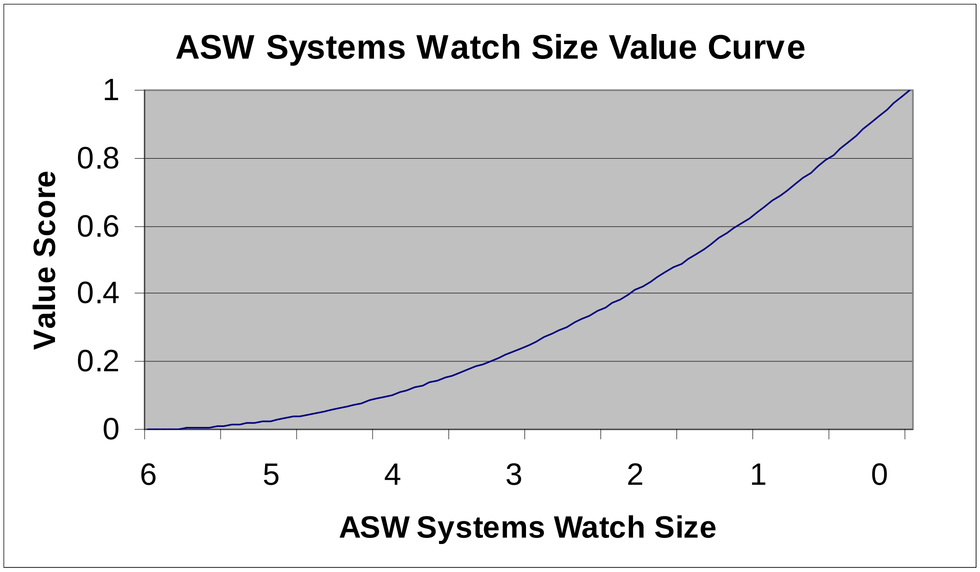


Figure 52. ASW Systems Manning per Watch Value Curve.

Because the four decision measures discussed above do not correspond directly to the measures and weights that were established in the value structure, nor do they represent the complete value structure, the weighting of these measures needed to be re-evaluated. In order to more directly match measures with functions and objectives the functions of classify, track, localize, and engage were rolled into the higher level function of prosecution. The four measures above were then assigned, or re-assigned weights based on the original value structure, stakeholder input, and the relative importance of the key function of detection established earlier. Table 26 contains a breakdown of how the updated measures match up with the primary functions of the system and the updated global weights that were used in the multi-attribute decision analysis.

Table 26. Updated Measures.

Detection	60%	
	Total Detection Time	40%
	Number of Sorties	20%
Prosecution	25%	
	Median Time to Prosecute	25%
Human Systems Integration	15%	
	Manning	15%

2. Raw Data Matrix

The data generated for each of the four decision measures was compiled and entered into the raw data matrix, shown in Table 27.

Table 27. Data Generated for Each of the Four Decision Measures.

Measures	Alternatives			
	ALT 1	ALT 2	ALT 3	P-3 ALT
Average Total Detection Time (hours)	18.08	18.49	30.57	16.62
Median Time to Engage (minutes)	537	80	80	214
Number of Sorties	2	2	1	29
ASW Systems Manning/Watch (w/o flight crew)	4	4	2	6

3. Decision Matrix

The decision matrix is a graphical tool used to combine value scores, global weights, and raw data and produce total value scores for each alternative based on Multi Attribute Utility Theory (MAUT).[54] The MAUT function, given below in Equation 1, is used to calculate the total value score *(U)* of a given alternative *(a_i)*.

[54] Sage [2000:p.403]

$$U(a_i) = \sum_{j=1}^{n} w_j U_j(a_i) \qquad \text{Equation 1}$$

In this function, w_j represents the global weight of a given measure and $U_j(a_i)$ represents the value score for the measure for a given alternative. Table 28 shows the individual value scoring of each measure for each alternative, the global weights associated with each measure, and the total value score calculated using the MAUT function.

Table 28. Individual Value Scoring.

Measure	Global Weights	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3 ALT
Average Total Detection Time	0.4	0.54	0.55	1	0.45
Median Time to Prosecute	0.25	0.02	0.93	0.93	0.63
Number of Sorties	0.2	0.96	0.96	1	0.03
ASW Systems Manning/Watch (w/o flight crew)	0.15	0.36	0.36	0.64	0
Total Value Score	1	0.47	0.70	0.93	0.34

4. Sensitivity Analysis

A sensitivity analysis of the weighted criteria was performed for the three recommended alternatives "to ensure that the weightings are not distorted."[55] Because "weights can make a difference between choosing one alternative over another,"[56] a decision analysis process was conducted on the sensitivity of global weights with respect to each recommended alternative depicted in Appendix E (Sensitivity Analysis Data). The sensitivity test will provide information as to how a change in our weighting or data for each factor in our decision matrix will affect the outcome. A graphical method was

[55] Forsberg [1996:P.154]
[56] Paulo, [2006]

also used in this process with the focus on the four primary evaluation measures that have the greatest impact on the decision. The four evaluation measures that were evaluated are average total detection time, mean time to engage, number of sorties, and ASW systems manning and watch. The rule of thumb for determining whether an evaluation measure is considered sensitive is "if the Point of Indifference is within 0.1 of the original global weight."[57]

Average total detection time was the first evaluation measure conducted in this analysis. The original global weight of this evaluation measure and the corresponding total utility score was plotted as shown in Figure 53. The point of indifference for this evaluation measure was determined to be 1.027 which is approximately 0.627 different than the original evaluation measure global weight of 0.40. This evaluation measure is considered as not sensitive since the point of indifference is not within 0.1 of the original global weight.

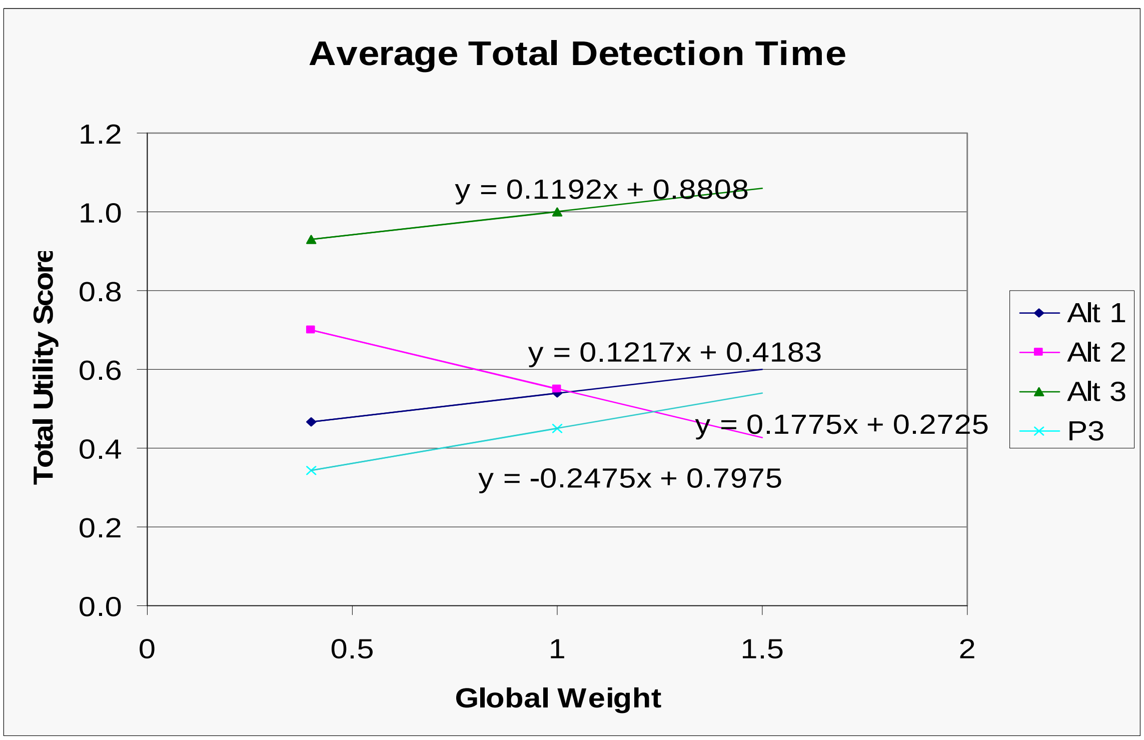


Figure 53. Sensitivity Analysis (Average Total Detection Time).

[57] Paulo [2006]

The mean time to engage was the second evaluation measure conducted in this analysis. The original global weight of this evaluation measure and the corresponding total utility score was plotted as shown in Figure 54. The point of indifference for this evaluation measure was determined to be 1.0 which is approximately 0.750 different than the original evaluation measure global weight of 0.25. This evaluation measure is considered as not sensitive since the point of indifference is not within 0.1 of the original global weight.

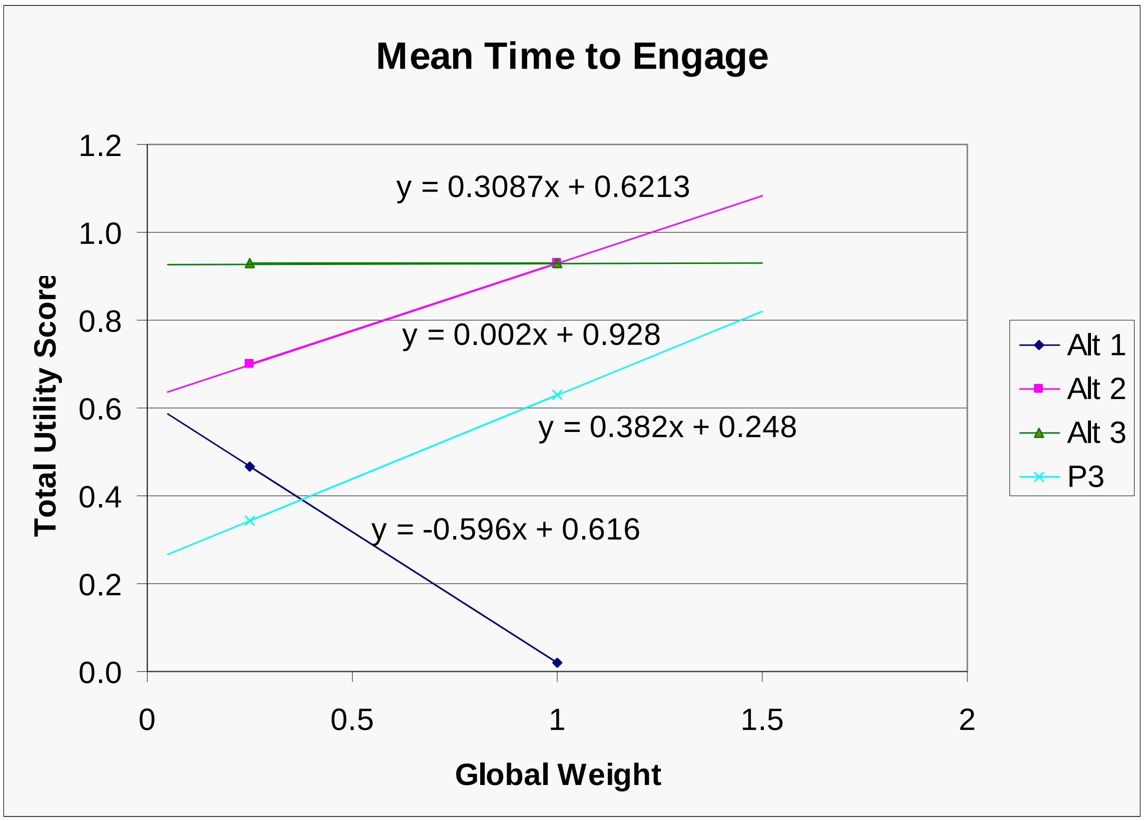


Figure 54. Sensitivity Analysis (Mean Time to Engage).

The number of sorties was the third evaluation measure conducted in this analysis. The original global weight of this evaluation measure and the corresponding total utility score was plotted as shown in Figure 55. The point of indifference for this evaluation measure was determined to be 1.17 which is approximately 0.968 different than the original evaluation measure global weight of 0.20. This evaluation measure is

considered as not sensitive since the point of indifference is not within 0.1 of the original global weight.

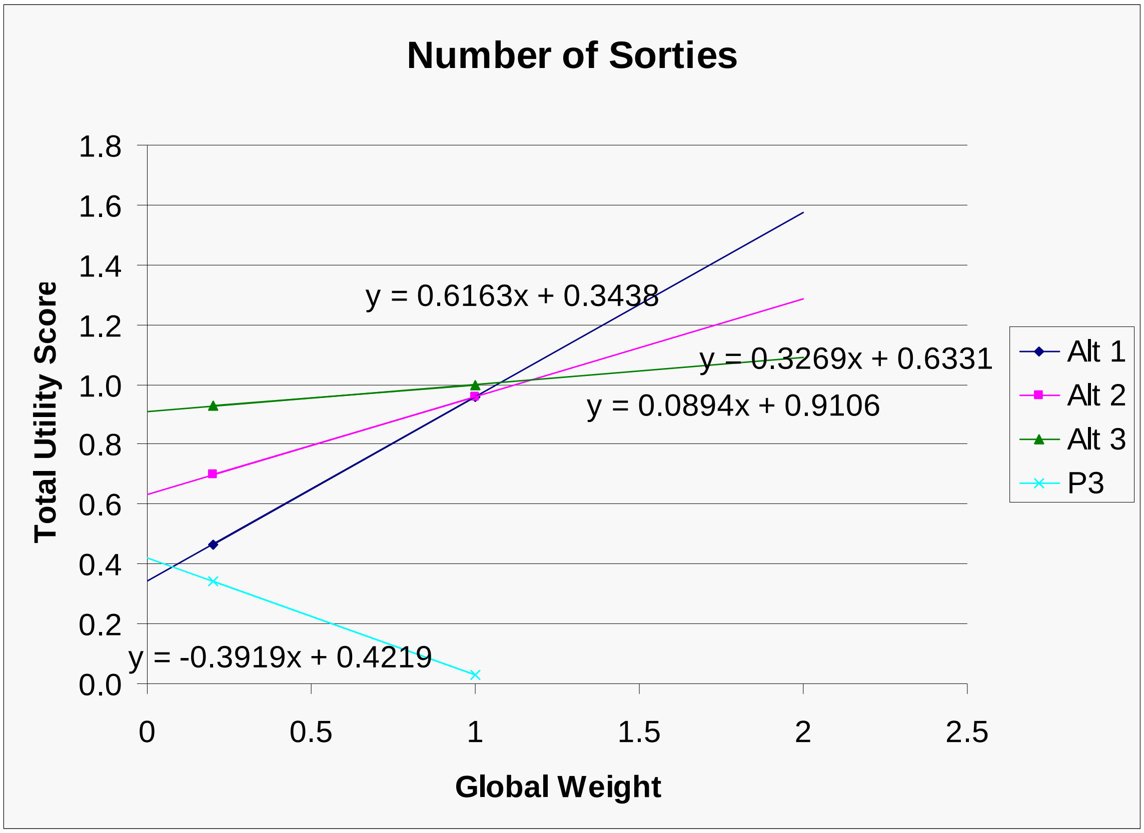


Figure 55. Sensitivity Analysis (Number of Sorties).

The ASW systems manning/watch was the last evluation measure conducted in this analysis. The original global weight of this evaluation measure and the corresponding total utility score was plotted as shown in Figure 56. The point of indifference for this evaluation measure was determined to be 1.0 which is approximately 0.850 different than the original evaluation measure global weight of 0.15. This evaluation measure is considered as not sensitive since the point of indifference is not within 0.1 of the original global weight.

The results shown in the above figures show that none of the evaluation factors are considered sensitive. This indicates that the assumptions that were made regarding the weighting of evaluation measures will not have an effect on our results. As such, if

the weights were not as accurate as initially thought and a change was required, the outcome of our study would not change. This provides more stability and confidence that our recommendations are correct.

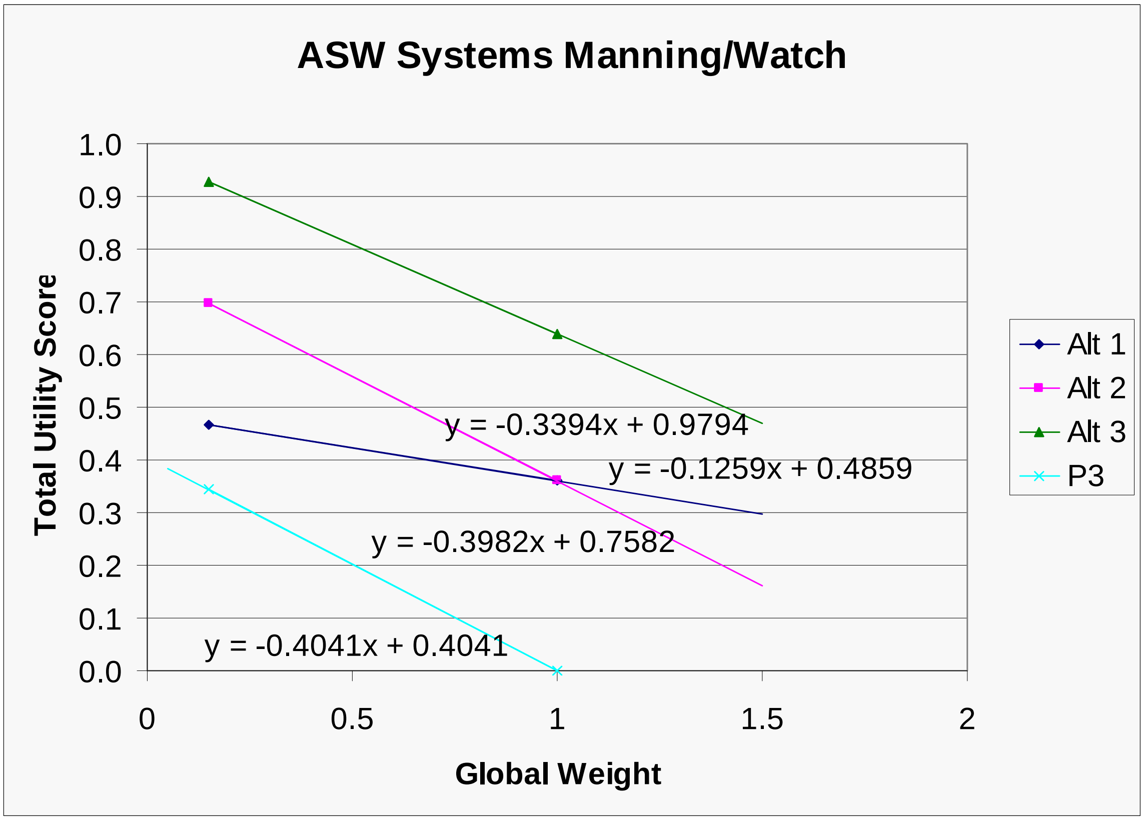


Figure 56. Sensitivity Analysis (ASW Systems Manning/Watch).

B. COST-VALUE ANALYSIS

Cost-value analysis was performed to consider the overall value, with respect to performance, and cost of that value in relation to the other alternatives. By plotting the total value score obtained from the decision matrix against the net present value obtained from the cost analysis it can be determined what relationship exists between cost and performance of the alternatives. When an alternative has a higher net present value and a lower total value score than another alternative it is considered “dominated” by that alternative. The P-3 was not included in this analysis because the purpose of the analysis was only to compare the proposed HAMR alternatives.

The results of the cost value analysis are presented in Table 29 and show the net present value (NPV) and total value score for each alternative. Figure 57 shows a graph of that data with the horizontal axis representing net present value from "best" to "worst" going left to right and the vertical axis representing total value score from "worst" to "best" going bottom to top. When interpreting the graph a rule of thumb is that alternatives closer to the bottom right corner of the graph perform more poorly in the cost-value analysis than alternatives closer to the upper left hand corner. The results show that Alternative 3 dominates all of the other alternatives, providing better overall performance and lower costs.

Table 29. Cost vs. Value Data.

Alternative	NPV (Mil)	Total Value Score
ALT 1	50.4	0.47
ALT 2	68.8	0.70
ALT 3	44.4	0.93

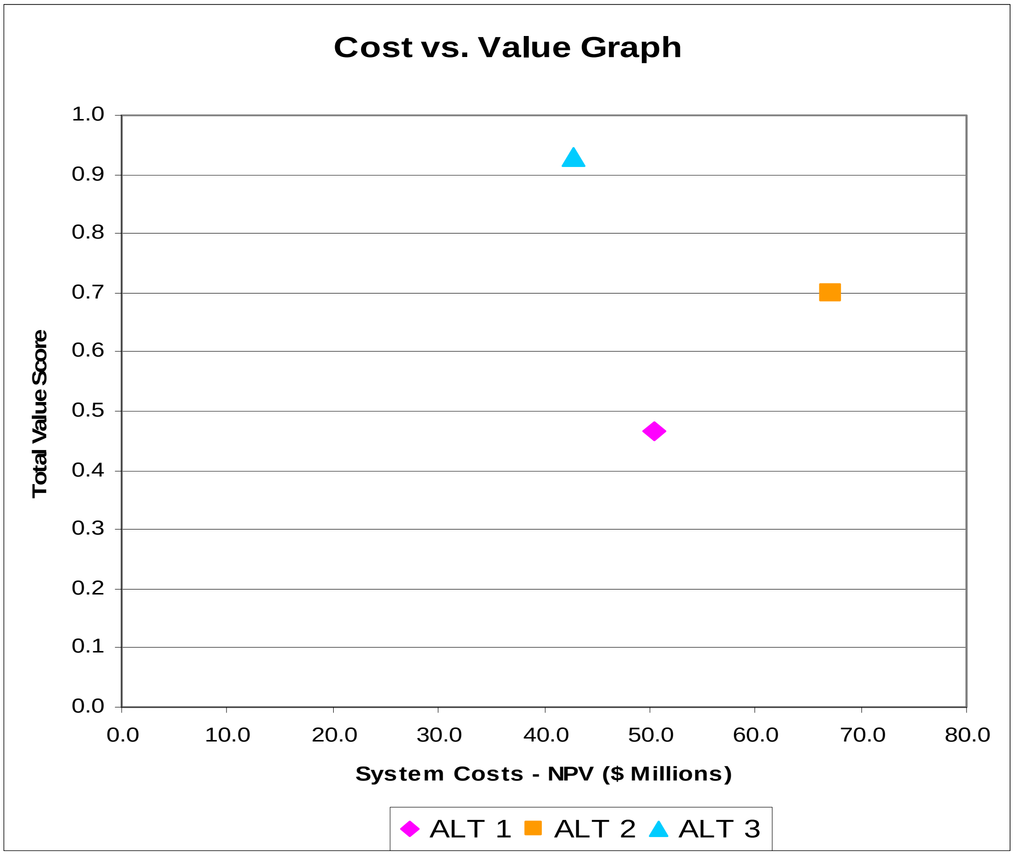


Figure 57. Cost Value Graph.

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

a) Modeling Conclusions

After the evaluation of alternatives, all three meet the stakeholders' minimum requirements and are suitable for the HAMR ASW mission module. Upon analysis of the modeling data, it became apparent that Alternative #3, the unmanned alternative, provides the best solution under the scenarios used. That is in part from its extensive sonobuoy capacity and the utilization of agile P-3 aircraft as its means to engage the targets. The modeling data clearly shows in the barrier scenario the HAMR ASW module carrying more sonobuoys has shorter time to detect than either a single P-3 or the other HAMR ASW module configurations. Due to the importance placed on barrier protection in the modeling scenario used, the HAMR was less effective than the P-3 in prosecution. However, in the given barrier scenario, the HAMR ASW solutions which direct P-3s for prosecution provide a statistically significant force multiplier. Based on this research, Alternative 3, HAMR ASW module is an effective force multiplier due to its suitability in loitering, detecting, and queuing of P-3 aircraft.

The model used in scenario C results in fewer sorties required for the unmanned HAMR ASW mission module compared to either a P-3 or all other HAMR module configurations. In the model scenario used, an ASW asset tracks a contact submarine approximately 1,300 NM. This model demonstrates, with greater persistence, a larger number of sonobuoys and greater capacity to carry fuel; Alternative 3 requires fewer sorties to complete the mission. Based on the model parameters, the results of this analysis yield the following sortie ratios: one sortie for Alternative 1, two sorties for both Alternatives 2 and 3 and twenty nine sorties for the P-3.

b) Manpower Conclusions

Manning was a key factor in the value structure defined by the stakeholders. With the Navy's clear trend toward reducing manpower, new weapon

systems must consider lower manning options. The P-3 crew performing ASW mission tasks totals six. In comparison all three HAMR ASW mission module alternatives require less manning. Alternative 1 requires four watch standers for ASW mission tasking to accommodate the launching of torpedoes. Alternative 2 also requires a crew of four in part to operate the towed array, while Alternative 3 only requires two operators in a remote station for ASW.

c) Decision Matrix Conclusions

The total value scores given in the decision matrix, shown earlier, represent the overall performance of each of the three HAMR ASW module alternatives and the P-3 platform. Alternative 3 clearly excelled in the simulations and analysis that was used to evaluate the alternatives with a score of 0.23, or 33% greater than Alternative 2. Looking at the value scores presented in the decision matrix there are two MOEs that Alternative 3 far exceeded all other alternatives, total time of detection and minimum crew size. For total time of detection the performance gain is a product of the increased sonobuoy field size Alternative 3 is capable of maintaining. The expanded sonobuoy field gave Alternative 3 greater detection range and more opportunity to detect enemy submarines transiting the barrier region. The crew size reduction for Alternative 3 was a result of removing complex and high maintenance systems requiring on site personnel and adding remote command systems allowing the module to be completely controlled by two operators on the ground.

In addition to the clear superiority of Alternative 3 in the simulations were performed, it is worth noting that all three HAMR platforms exceeded the total value score of the P-3. When comparing the P-3 to the alternative with the nearest total value score it is interesting to note that its greatest advantage over the P-3 was its persistence. The extended persistence of the HAMR platform allows it to spend more time in its primary mission and less time in transit. The effects of this are evident in the value scores of the total detection time and total number of sorties MOEs.

d) Cost and Logistics

Cost and logistics data was collected on the various components of the alternatives. This information was obtained by various means of collaboration with

program office, SMEs, technical manuals, and Navy Supply System. Once the collected information was compiled, an analysis was performed which allowed a roll up of weight, power, space, LCCs, and manning estimates for analysis.

Component footprints were estimated and totaled to establish a physical size for each alternative. The size estimate was used by stakeholders with an estimate of the module's outline for HAMR aircraft construction considerations. Likewise, weight was totaled to ensure the lift capability envelope was not exceeded by the alternatives under consideration. Power requirements were summarized to provide the stakeholders with an estimate to guide the design of the HAMR power system. Life cycle costs were estimated for the life of the module of 20 years. It includes acquisition of the systems, integration into the system, ongoing technical support, two technical insertions, and ultimate disposal at the end of life. The overview of the life cycle cost and logistics data is shown in Table 30. Alternative 1's cost total of $50.4M per unit is largely impacted by the hard kill components. Alternative 2 contains a thin line towed array, which is the single largest impact of cost to any of the alternatives. Alternative 3 is the lowest cost alternative at $44.4M. Alternative 3 is the smallest, lightest, consumes the least amount of power, and is the least cost leader.

Table 30. Overview of Alternative Details.

	Size (ft^3)	**Weight (tons)**	**Power (kW)**	**Life Cycle Cost ($M)**	**Manning**
Alternative 1	**814**	**28.9**	**8.9**	**$50.4**	4
Alternative 2	**763**	**26.9**	**9.4**	**$68.8**	4
Alternative 3	**677**	**19.4**	**8.6**	**$44.4**	2

e) Cost Value Analysis Conclusion

Examining the cost-value analysis presented earlier it is immediately clear that Alternative 1 and Alternative 2 are both dominated by Alternative 3. This is an interesting outcome because it seems to indicate that the costly systems used in Alternatives 1 and 2 for detection and engagement added little value in our analysis. It is

difficult to determine whether our analysis simply did not use the full capability of these systems or that simply using sonobouy fields and focusing on detection above all else is the most effective and cost efficient way for the HAMR to conduct airborne ASW. This is an area that should be examined in future research.

f) Risk Conclusions

Many of the systems used in Alterative 1 have previously been integrated into the P-3 and provide a minimum of risk. Inserting new technology in the form of the tactically integrated sensor combat system (TIS) into a unique airborne application like Alternative 1 yields medium risk. While TIS is fielded on all of the Navy's aircraft carriers, it has not been applied to an airborne environment. Some of the other technologies considered in the ASW modules, have not been fielded from an airborne platform. Alternative 2 applies the use of a thin line towed array which is currently used in both shipboard and submarine applications, but airborne use of this system is unproven and affords a higher level of risk. The balance of the technology selected for Alternative 3 is adapted from other airborne platforms that are currently fielded, hence presenting marginal risk in application to an ASW airship platform.

g) Summary

Based on our analysis, the unmanned ASW mission module offers the lightest weight, lowest cost, lowest risk, and best performance. For these reasons, the recommendation is Alternative 3.

2. Recommendations

a) Recommended Systems

The following recommendations are based on research utilizing the SEDP as presented in the value systems design, alternative generation, modeling and simulation, decision analysis and conclusion sections of this paper. All research was the result of stakeholder's effective need for a persistent airborne asset for detecting, communicating, tracking, localizing, classifying and engaging ASW threats. The subsequent recommendation of Alternative 3, the unmanned lightweight sensor platform meets these

requirements while providing the overall best performance, lowest cost with the minim number of operators.

As previously noted the hybrid airship is not within scope of project as it is simply the host for the module and only power and weight of the module are the two platform constraints defined. This alternative uses the P-3 or other platforms for prosecution. Alternative 3 is comprised of a tactically integrated sensor combat system (TIS). TIS is comprised of a COTS based hardware platform with government owned software and is the center of the combat and control system of the module. A derivative is currently fielded on every USN Aircraft Carrier as part of the ship defense system. It provides the ability to collect and correlate numerous sensor inputs from internal sensors, buoys, and other sensor platforms in theater and present them on a remote display for the operators; offering a common operating picture.. It employs tactical decision aids (TDAs) to automate and improve the decision making process for the remote platform operators. It is fully capable of communicating raw date, rendered data, tracks and all associated metadata over the communications alternatives options selected for the module. It can be fielded in either a classified or unclassified version as needed.

All sensing in this alternative is leveraged from currently fielded Navy capabilities, in part, to ensure technical maturity and to simplify training and logistics supportability. The capabilities begin with millimeter surface scanning radar for mast detection LIDAR for shallow water detecting and ranging of targets. Magnetic Anomaly Detecting for submarine sensing at depths which exceed LIDAR capability. The electro-optical visual light and infrared camera system provides a visual component to the modules sensing systems. All sensing inputs, whether visual, tracks, contacts or information provided from other contributing assets can be correlated with the buoy fields providing a common operating picture.. Platform location, direction, altitude and ground speed information is provided via GPS and integrates the map information contained within the TIS mapping module. Acoustic monitoring is acquired by standard COTS sonobuoys currently deployed by the Navy. The ASW module has an enhanced capability to carry up to 2160 sonobuoys and is equipped with two 120-channel remotely operated receivers and directional antennas which permit simultaneous monitoring more than one buoy field, significantly contributing to the 24/7 persistence offered by this

solution. Preset sonobuoys will be dispensed via two modified P-3 buoy launcher systems operated by a COTS computer providing remote operators the ability to select the sonobuoy types needed for a mission. Automatic in-flight placement is accomplished by uploading the required field coordinates via LINK 16 communications or satellite communications to the COTS launcher computer. The system will automatically dispense the pre-selected buoys, based on the GPS derived coordinates. Pre-set templates may be selected, if desired, to simplify or expedite placement.

To comply with stakeholders limitations of weight limits, Alternative 3 weight is estimated at 19.4 tons; easily meeting the 50 ton lift capacity constraint given by stakeholders. While there were no limits on package size, the selected alternative will require approximately 677 cubic feet within its enclosure.

b) Recommended Area of Future Research

The in-depth analyses of the systems and HAMR platform have answered many questions about the HAMR craft and ASW mission module. However, there still exist unknowns which have not been resolved. The HAMR ASW mission module has several unique capabilities that provide many areas for future research. Several of these research topics have been categorized into operational and technical areas in the following paragraphs. Increased manpower and funding for future research in these areas will provide strategic information to decision makers and will contribute greatly to the HAMR ASW mission module.

Operational Areas

The operational areas of future research focus on the operational elements and specific strategies that are provided by the HAMR ASW mission module. The advantages of the HAMR platform must be thoroughly understood as well as the disadvantages. The data that results from these operational research topics will provide information to decision makers for use in future design iterations or strategic operational decisions.

- A standard ASW scenario that would provide a baseline for a comparative analysis is desired. The scenario would be provided by the Navy's ASW taskforce and may be a situation within which the HAMR platform could be dropped into. This standard scenario would provide a basic reference point for comparison.
- Additional littoral scenarios are desired to fully understand the operational capability and overarching strategies that can be employed using the persistent HAMR craft. There are many questions in the littoral realm that require answers. For instance, given the air born nature of the HAMR what considerations must be made for detection in a littoral area. What is the increase risk of detection due to the proximity of land? What are additional active search capabilities that could be utilized by the HAMR in littoral areas?
- Address new operational capabilities of P-8 and how it can complement the HAMR. The additional capabilities of the new P-8 may be leveraged to provide increases functionality to the HAMR platform for force multiplication purposes. One example of this is that the hard kills which are delegated to the P-3 by the HAMR would instead be handled by the P-8. Increases in speed and payload of the new P-8 would need to be factored into a new set of models and simulations.
- Analyze how decreases in habitability of unmanned solutions provide increased space savings. How can these space savings be utilized effectively? Which systems should fill these spaces? Also a more detailed analysis of the process changes required for the unmanned solutions should be undertaken. Specifically, what kinds of safeguards should be employed to ensure automation does not result in unintended effects.
- For the unmanned solution determine what increase of mission hostility is acceptable due to the decrease of personnel? Given that there are no human lives at stake in the unmanned solution what types of increase mission risks are permitted and how deep into enemy territory may a HAMR travel? This raises important issues that can significantly alter the HAMR's CONOPs.
- How can the unmanned solution provide increased mission endurance? Without local manning requirements several teams of remote pilots and sensor

operators could remotely control the craft from a base hundreds of miles away. Consequently, there is a significant potential for increased mission endurance, the extent of which could be better understood through future simulations.

- Additional open water scenarios for simulation and modeling the HAMR ASW module are needed. In an effort to know more about the operational capability of the HAMR ASW mission module, a myriad of open water scenarios should be considered and the HAMR's performance in these situations should be collected. Testing the performance of the HAMR in all types of situations would further define both its strengths and limitations.
- There should be a detailed examination into specific strategies which could take advantage of the HAMR's out of water detection capability. The persistent and airborne nature of the HAMR provides several advantages in ASW warfare. Since the HAMR does not traverse through the water it will not be creating vibrations through the water medium via propeller rotation, movement of engine components, nor from a hull colliding with waves. Therefore, the conventional method of detection by listening passively for vibrations in the water is not applicable to the HAMR. It may theorize that a submarine would have to extend its periscope to visually identify the HAMR. If so, an attack solution would most likely already be enroute to deal with this submersible. This is one of several advantages that may be found if this research topic is pursued.
- A detailed analysis of probable counter measures to the HAMR's capabilities that will likely be used by the enemy provides an interesting research topic that could be explored. The technologies and strategies of war are always evolving and it is necessary to anticipate what possible counter measures might be employed. In doing so we will better understand how to counter these enemy strategies and identify strategic weaknesses of the HAMR and its methods of operation.

Technical Areas of Future Research

There are several areas of technical research that could be given a closer analysis. Technical areas of research are primarily system specific topics. Many questions were

answered by the analysis performed by the HAMR ASW team, however continued analysis may be given to the areas specified below.

- Additional research should be given to understanding the automation interfaces necessary for unmanned systems. The unmanned solution consists mostly of sonobuoys which can be automated with a sonobuoy dispenser attached to the bottom of the air frame. However, the control interfaces that are required to initiate deployment of sensors would need to be designed. Likewise, the automation control interfaces for the previously manned systems such as the EO/IR, LIDAR and MAD systems will require further research.
- Conduct research on how much bandwidth is needed for multiple system transmissions. One technical question which could be given attention is the amount of bandwidth necessary to use all of the systems simultaneously. How will this bandwidth be relayed back to headquarters and how much performance degradation in wireless bandwidth is expected under varying weather conditions?
- What technical considerations should be made to incorporate the HAMR ASW mission module into the LCS architecture? What interfaces would need to be developed to affectively integrate the HAMR into the LCS architecture and how could the unmanned solution (Alternative 3) best be utilized within this structure?
- Examine the functionality and communication interfaces that may be provided by the P-8. How does the new functionality of the P-8 factor into our models in terms of delivering the Mk-54 on target. What integration interfaces should be developed to communicate with the new P-8? What additional technological innovations of the P-8 can be incorporated into the HAMR ASW mission module?
- Various risks which were assumed to be of minimal priority could be more closely examined. For instance, the interference or lack thereof of multiple sensors suites and auxiliary systems on a single air born platform should be analyzed. The operational environmental and persistent characteristics of the HAMR craft expose some interesting concerns as well. For example, how will transmitters and receivers function when the HAMR is engulfed in a

thunderstorm? These previously unmitigated risks provide an excellent area for observation.

B. PHYSICAL ARCHITECTURE/COMPONENT DETAILS

The focus of the component detail section is to provide system and component descriptions from a general standpoint. An analysis of each system provides an overview of its capability and thus the overall potential of the HAMR. Included within some of the system descriptions are the subsystems and the external components needed to operate the system. Appendix H reflects systems that are centered on the unmanned solution (Alternative-3), which is the recommended alternative.

LIST OF REFERENCES

"Airborne Applications (ONR)." http://polatomic.com/default.asp?ID=139. 2007.

Allocca, David. HAMC Capabilities Stakeholders Questionnaire. 2007.

Analyst Guide for the Employment of the Naval Simulation System (NSS v3.3). Metron, SPAWARSYSCOM, PMW-153, CNO N6, N6M. August 31, 2002.

"AN/USQ-125(V) Link-11/TADIL-A Data Terminal Set/Link-22 SPC." http://www.drs.com/products/ANUSQ_125.aspx?cat=c3_systems&subcat=Sub_Cat. 2008.

"Approved NAVY Training System Plan for the NAVY Consolidated Sonobuoys." Sept 1998.

Benedict, Terry. Rear Admiral USN. Program Executive Office – Integrated The weapons System (PEO-IWS 5). Briefing to the National Industrial Defense Association Joint Undersea Warfare Technology Conference: Understanding and Addressing the Evolving Missions: The Critical Challenges. April 2008.

Blanchard, Benjamin S & Fabrycky, Wolter J. Systems Engineering and Analysis. Prentice Hall: 4 edition (May 15, 2005).

Boensel, Matt, Naval Postgraduate School. "Interview with Matt Boensel." 6 June 2008.

Boyd, Ken, SPAWAR Systems Center San Diego. RF and Communications Division "Communication Systems on a Blimp." E-mail 17 April 2008.

Boyd, Ken, SPAWAR Systems Center San Diego. "RE: Comms on a blimp." E-mail 30 April 2008.

Bretz, Robert J (Bud), JR NPRI. "RE: Towed Array and Handler dimensional data and cost estimates." E-mail from Bud Bretz. 14 April 2008.

China's Navy 2007. Office of Naval Intelligence (ONI) 2007.

Clark, Vern, ADM U.S. Navy. *Sea Power 21 Projecting Decisive Joint Capabilities*. Naval Institute Proceedings. October 2002. (Found on the web at http://www.navy.mil/navydata/cno/Proceedings.html).

"Command, Control, Communications, Computers, and Intelligence. http://www.navy.mil/navydata/policy/vision/vis02/vpp02-ch3u.html. 2008.

"Common Data Link [CDL]." http://www.globalsecurity.org/intell/systems/cdl.htm. 2008.

Course Notes from SE 4001. Course website (NPS Blackboard). 'Systems Engineering Design Process.' 2008.

Davis, Paul H. CIV NAVAIR "RE: Dipping Sonar Research" E-mail from Paul Davis. 26 March 2008.

Dullea, Jim "Synthetic Aperture Sonar" Phone interview with Jim Dullea. 15 April 2008. Mullen, Linda NAVAIR "RE: LIDAR use for a blimp." E-mail from Linda Mullen. 22 April 2008.

Elkins, Bill, Kaman "RE: Lidar questions." E-mail from Bill Elkins. 30 April 2008.

Finnigan, Charles. "RE: ALQ-217 specification requirements." E-mail from Charles Finnigan.

Forsberg, Mooz, and Cotterman. Visualizing Project Management. July 9, 1996.

Gelatka, William CIV NAVAIR. "RE: MAD Questions." E-mail from William Gelatka. 23 April 2008.

Green, John M. "Establishing System Measures of Effectiveness."

Harris, Kaman Inc. "April Showers_Inf.pdf LIDAR for Anti-submarine Warefare." 25 January 2001.

http://rfdesign.com/military_defense_electronics/news/radios_bring_communications/. Defense Electronic News, "JAM-resistant Link-16 radios bring communications versatility to the battlefield." Oct 11, 2006.

https://www.ex.crane.navy.mil/sonobuoy/PROD.HTM#difar. 28 April 2008.

Jaffee, M. "Star Safire III.pdf." 23 March 2007.

Jane's Fighting Ships 2001-2002. Foreword. http://www.janes.com/press/press/pc010430.shtml.

Kaman Aerospace Corporation Electro-Optics Development Center. White Paper on Littoral Warfare LIDAR. <http://www.kamanaero.com>. 28 Mar 2003.

Kuhlman, CAPT Gary, Polatomic "AN/ASQ-233 Information" E-mail from Gary Kuhlman. 30 April 2008.

Kuhlman, CAPT Gary. Interview with CAPT Kuhlman. 1 April 2008.

Lockheed Martin website, http://www.lockheedmartin.com/products/p3/index.html 1 April 2008

Lozano, Omar., Raytheon, "Radar for a ASW blimp" Email from Omar Lozano. 1 May 2005

McGovern, Janet. AN/ASQ-233 Magnetic Anomaly Detection Light Weight Towing System for Light Weight Helicopters and Small, Vertical Take Off Unmanned Aieral Vehicles. http://www.navysbir.com/n08_1/N081-001.htm. 10 Dec 2007.

Napolitano, Michael K CDR CNAF. RE: "P-3 question." 9 June 2008

Naval Operations Analysis, Third Edition, Chapter 7, Edited by Daniel H. Wagner, W. Charles Mylander, and Thomas J. Sanders. Naval Institute Press. 1999.

Nicholas, J. Private telephone conversation. 17 April 2008.

NSWC Crane PMA 264 Air ASW system "Sonobuoys" https://www.ex.crane.navy.mil/sonobuoy/PROD.HTM#difar. 28 April 2008

Owego, Steve, Lockheed Martin "APY-217 Systems Technical Description by prepared for Matt Cawley." 6 May 2008

P-3C *Orion* long range ASW aircraft. (2007). http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=1400&ct=1. Retrieved from January 20, 2008.

Paulo, Eugene. Notes for SI4008 (Systems Engineering and Integration). Naval Postgraduate School (unpublished). 2006.

Paulo, Eugene. Course SE4007 Lecture Notes. "Value (or Objectives) Hierarchy: Functions, Attributes, and Metrics." Winter Quarter 2006.

"The Quality Toolbox." http://www.asq.org/learn-about-quality/idea-creation-tools/overview/affinity.html. 2008.

Rarig, Scott. HAMC Capabilities Stakeholders Questionnaire. 2007.

Raytheon Fact Sheet – Multi-Mission Maritime and Overland Surveillance Radar "AN/APY-10." May 2007.

SI 4008 Class Presentation by Professor Eugene Paulo on 19 May 2006. 'Sensitivity Analysis,' Slide 3.

SI 4008 Class Presentation by Professor Eugene Paulo on 19 May 2006. 'Sensitivity Analysis,' Slide 10.

Sage, "Introduction to Systems Engineering." March 27 2000.

Slocum, Robert. Polatomic, "Geomagnetic Reference Sensor System (GRSS) for Air Anti-Submarine Warfare (ASW)." 19 December 2007.

Statter. HAMC Capabilities Stakeholders Questionnaire. 2007.

Sumner, Christopher B. NSWC Crane "Produce Sonobuoy Specification" E-mail from Christopher Sumner. 21 March 2008.

Sumner, Christopher B. NSWC Crane "Produce Sonobuoy Specification" E-mail 11 April 2008.(ppt). WEPS-(09) C4ISR Info Warfare.ppt.

Task Force ASW. *Anti-Submarine Warfare Concept of Operations for the 21st Century*. White Paper. 2004

Waickwicz, J J. RADM U.S. Navy, *ASW Readiness and Mine Warfare Way Ahead*. Briefing.. Nov 20, 2006.

U.S. Navy Fact Sheet – Fast Attack Submarines. 13 November 2007. http://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=100&ct=4

U.S. Navy Fact Sheet – SSGN. 8 November 2007. http://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=300&ct=4

U.S. Navy Fact Sheet – SSBN. 11 November 2007. http://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=200&ct=4

Vosilla, John A. Northrop Grumman Corporation, "RE: Ramics." E-mail from John Vosilla.

APPENDIX A

Draft Mission Statement: Develop an Anti-Submarine Warfare (ASW) Mission Capability for the HAMR 50-ton demonstrator.

Questions for Stakeholders:

- Below is a short list of systems that have been proposed as candidates to for inclusion in the HAMR ASW Mission Capability (HAMC), for all of the systems that you have knowledge of, could you provide a point-of-contact (POC) who could provide technical information about that system?

    - Dipping Sonar
    - Sonobuoys Sensors **Mitch Haggard 5-2237**
    - Magnetic Anomaly Detection (MAD) sensor system
    - Anti-Torpedo Sensor/Weapons
    - Mk 54 Torpedo Weapons System
    - Surface Search Radar
    - Periscope Detection
    - Thin Line Towed Array
    - Sensor Processing **Corey Countryman 5-7708**
    - ASW Combat System **Corey Countryman 5-7708**

    - Are there any other systems that you would recommend for consideration in an Analysis of Alternatives (AoA)? **AIS receivers, UAVs, net-torp, heavy-weight torps, environmental sampling & analysis, IR sensors, Specific Emitter Identification (SEI), SAR/ISAR, Video Imaging, self defense counter measures (chaff, jamming, etc),**

- What do you see as the critical functional capabilities this module should have in order to be successful? **Self contained sensors, analysis capabilities, communications (to/from sensors, responders), response capability, and associated infrastructure support (crew habitability, power, space)**

- Roughly, how much procurement money do think will be available for the design and deployment of the HAMC? **$5M sensor integration, $15M analysis/C2 suite, $5M comms integration, $15M weapons suite, and $15M infrastructure (crew space, magazine, power, etc.)**

- With what networks/data links should the HAMC have connectivity? **Link 11/14/16/22, sonar receiver channels, potential UAV control/data channels, TCDL**

- Which of those networks or data links should be provided by the Airship? **HAMR would be a node for Link and sonar channels, potentially on the UAV control/data channels would be organic to HAMR, TCDL.**

- Should the HAMR Payload Module be capable of being disassembled for transportation and storage (e.g., two 25-ton sections that can go on 2 trucks)? **Yes, two may be wrong number though.**

- In what ways could the HAMC potentially increase, or fill gaps, in ASW operational capability**? Improved persistence/loitering, increased search speed, more integrated capability (more sensors, more analysis capability), quicker response, greater stealth, and more ASW related payload (equipment, sensors, weapons, personnel)**

- What do you see as the major hurdles to employing HAMC? **Establishing the platform due to perceived competition with existing platforms, initial cost for fielding the platform, initial cost for fielding HAMC (and other mission packages), facilities, hanger space, manning, training, identifying an "owner", overcoming the resistance to change and embracing innovation.**

- From what you currently know or envision about the HAMC, please provide a brief description of an operational scenario or concept of operations (CONOPS). **Given Blue Force air superiority and knowledge of regional/local weather conditions throughout deployment of HAMC, the following could apply:**

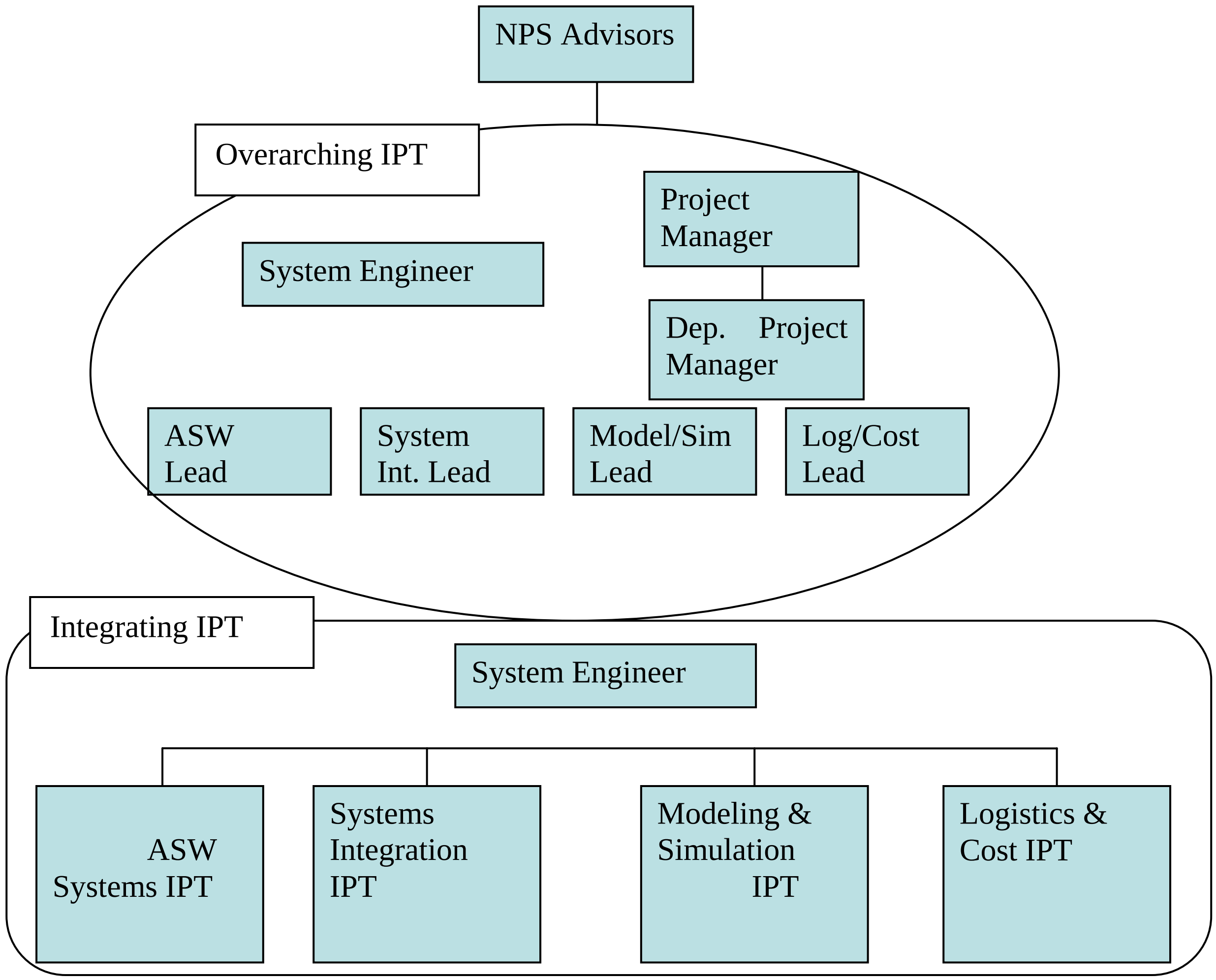
  - **Stand alone HAMC Area ASW – in conjunction with a CSG (with an appropriate stand-off for safety from submarine attack, say a couple hundred miles) which is tasked to defend the HAMC from air or surface threats, HAMC conducts independent searches and conducts/coordinates ASW attacks (by other ASW platforms including other HAMCs) in order to clear an area or prevent intrusion by a submarine.**

  - **Coordinated HAMC Area ASW – deployed with other ASW platforms, i.e. ships and subs, HAMC provides either in-depth (e.g. outer) ASW defense or sector (e.g. flank protection) defense for either a CSG or ESG.**

  - **Littoral Patrol – deployed in stand alone mode, protected by either sea assets or shore based assets, HAMC conducts searches or searches and attacks on submarines. Other ASW platforms (e.g. helos, fixed wing, subs, or ships) can launch attacks if HAMC is only in a search mode. Monitors shipping**

in/out of port; identifies/tracks suspect platforms; provides communications/sensor data relay for shore base units; deploys/monitors sensors.

APPENDIX B


NPS Advisors
Overarching IPT
Project Manager
System Engineer
Dep. Project Manager
ASW Lead
System Int. Lead
Model/Sim Lead
Log/Cost Lead
Integrating IPT
System Engineer
ASW Systems IPT
Systems Integration IPT
Modeling & Simulation IPT
Logistics & Cost IPT

APPENDIX C

System #	System	Organization	Contact Info
1	*Manual Torpedo Preset System - MK437*	NUWC Keyport	John Kenney
2	*TIS - SAAS & SPS*	NUWC Keyport	Mike Newberry
3	*Comms - JTRS (PRC-148)*	SPAWAR	
4	*GCCS-M (USQ-119)*	SPAWAR	
5	*Comms – SATCOM (PRC-117F)*	SPAWAR	
6	*Comms - Link 11 - AN/USQ-125*	SPAWAR	Dr. Ken Boyd Code 552 - RF Comms & Systems Division Phone: (619) 553-6801 Email: ken.boyd@navy.mil
7	*Comms - Link 16 – AN/URC-107 (V)*	SPAWAR	
8	*Comms - Link 22*	SPAWAR	
9	*Comms - Class I Common Data Link (CDL)*	SPAWAR	
10	*Automated Digital Network System (ADNS)*	SPAWAR	
11	*Sonobuoy Receiver (ARR 970)*	SPAWAR	
12	*Sonobuoy Dispenser (Integrated with TIS)*	NUWC Keyport	
13	*LW Torpedo - MK54*	PMS 404	John Kenney
14	*Super Cavitating Munitions - MK258*	NSWC Dahlgren	
15	*Smart Depth Bomb (Modified JDAM) MK 82/BLU-111*	NAVAIR	
16	*RAMICS*	NSWC Dahlgren Northrop Grumman	Vito Jimenez Phone: 516-575-5119 Email: vito.jimenez@ngc.com
17	*Towed Array - TB29A Thin Line*	NUWC Newport	Robert “Bud” Bretz Phone: (401) 832-3350 Email: bretzrj@npt.nuwc.navy.mil
18	*Towed Array - Handler (OA-9070B)*	NUWC Newport	
19	*Dipping Sonar*	NAVAIR	Paul H. Davis MH-60R Acoustics Engineer / ALFS Engineer Phone: (301) 995-7339 / (301) 342-2115 Email: paul.h.davis@navy.mil
20	*Synthetic Aperture Sonar*	OEM	Jim Dullea Applied Signal 703-417-5311
21	*SSQ 53F Passive Sonobuoy*	NSWC Crane	Christopher Sumner Phone: (812) 854-2008 Email:
22	*SSQ 62E Active Sonobuoy*	NSWC Crane	
23	*SSQ 101 ADAR Sonobuoy*	NSWC Crane	

24	*SSQ-110 Extended Echo Ranging Sonobuoy*	NSWC Crane	christopher.sumner@navy.mil
25	*MAD AN/ASQ 233*	NAVAIR	Bill Gelatka Phone: (301) 342-2552 Email: omar@raytheon.com
		Polatomic Inc.	Gary Kuhlman Phone: (972) 690-0099 ext. 12 Email: GaryKuhlman@polatomic.com
26	*RADAR - APY-10 (Surface Search Periscope)*	NAVAIR	
		Raytheon	Omar Lozano Phone: (972) 952-5303 Email: william.gelatka@navy.mil
27	*EOIR - HD Telescope Camera (Star Safire 3)*	NAVAIR/ FLIR	Jeff Nicholas (360) 921-9660 Jeff.nicholas@flir.com
28	*ESM (AN/ALQ-217)*	NAVAIR	
		Lockheed Martin – Owego	Charles Finnigan Senior Manager, Business Development Phone: 607-751-4081 Email: charles.finnigan@lmco.com
29	*LIDAR - April Showers*	NAVAIR	Brian Concannon (301) 342-2034 brian.concannon@navy.mil
		Kaman Aerospace Corp.	William P. Elkins Chief Optical Engineer Bill.Elkins@Kaman.com (520) 295-2187

APPENDIX D

Alternative 1

System #	Function	Procurement	Integration	Logistics	Operational	Maintenance	Disposal	Total
1	CS	$32,657	$0	$75,358	$194,427	$17,561	$8,500	$328,503
2	CS	$719,942	$500,000	$1,661,291	$583,280	$399,123	$4,250	$3,867,886
3	CS	$296,883	$100,000	$685,069	$583,280	$159,649	$17,000	$1,841,881
4	CS	$148,442	$500,000	$342,534	$583,280	$79,825	$12,750	$1,666,831
5	CS	$296,883	$75,000	$685,069	$583,280	$159,649	$12,750	$1,812,631
6	CS	$296,883	$75,000	$685,069	$583,280	$159,649	$12,750	$1,812,631
7	CS	$59,377	$35,000	$68,507	$583,280	$15,965	$12,750	$774,878
8	CS	$593,767	$100,000	$85,634	$48,607	$31,930	$8,500	$868,437
9	CS	$1,187,534	$50,000	$342,534	$0	$15,965	$1,700	$1,597,733
10	HK	$0	$400,000	$856,336	$583,280	$0	$0	$1,839,616
11	HK	$148,442	$30,000	$342,534	$0	$0	$1,700	$522,676
12	HK	$59,377	$400,000	$137,014	$583,280	$0	$3,400	$1,183,070
13	HK	$2,968,834	$250,000	$1,541,404	$583,280	$159,649	$34,000	$5,537,168
14	SBS	$0	$100,000	$0	$0	$0	$6,800	$106,800
15	SBS	$0	$100,000	$0	$0	$0	$6,800	$106,800
16	SBS	$0	$100,000	$0	$0	$0	$6,800	$106,800
17	SBS	$0	$100,000	$0	$0	$0	$6,800	$106,80
18	SBS	$148,442	$600,000	$342,534	$194,427	$79,825	$8,500	$1,373,727
19	SRFS	$2,968,834	$1,000,000	$2,860,162	$194,427	$159,649	$34,000	$7,217,072
20	SRFS	$705,098	$200,000	$1,627,038	$194,427	$79,825	$8,500	$2,814,887
21	SRFS	$3,859,484	$800,000	$1,712,672	$194,427	$41,509	$25,500	$6,633,591
22	SRFS	$4,453,251	$1,200,000	$1,712,672	$388,853	$478,947	$42,500	$8,276,223
	Element Totals	$18,944,131	$6,715,000	$15,763,429	$6,659,113	$2,038,719	$276,250	$50,396,642

Alternative 2

System #	*Function*	*Procurement*	*Integration*	*Logistics*	*Operational*	*Maintenance*	*Disposal*	*Total*
1	**CS**	$735,156	$500,000	$1,636,203	$583,280	$399,123	$4,250	$3,858,012
2	**CS**	$151,579	$10,000	$337,361	$388,853	$79,825	$12,750	$980,368
3	**CS**	$303,157	$100,000	$674,723	$583,280	$159,649	$17,000	$1,837,809
4	**CS**	$151,579	$500,000	$337,361	$583,280	$79,825	$12,750	$1,664,795
5	**CS**	$303,157	$25,000	$674,723	$583,280	$159,649	$12,750	$1,758,559
6	**CS**	$303,157	$75,000	$674,723	$583,280	$159,649	$12,750	$1,808,559
7	**CS**	$60,631	$35,000	$67,472	$583,280	$15,965	$12,750	$775,099
8	**CS**	$606,314	$100,000	$84,340	$48,607	$31,930	$8,500	$879,691
9	**CS**	$1,212,629	$50,000	$337,361	$0	$15,965	$1,700	$1,617,655
10	**HK**	$0	$0	$0	$1,749,840	$0	$0	$1,749,840
11	**SBS**	$3,789,464	$1,000,000	$1,686,807	$388,853	$39,912	$85,000	$6,990,037
12	**SBS**	$817,009	$750,000	$1,818,378	$0	$860,509	$34,000	$4,279,896
13	**SBS**	$1,515,786	$500,000	$1,686,807	$194,427	$159,649	$12,750	$4,069,419
14	**SBS**	$6,499,942	$1,200,000	$1,686,807	$194,427	$63,333	$20,400	$9,664,909
15	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
16	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
17	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
18	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
19	**SBS**	$151,579	$600,000	$337,361	$194,427	$79,825	$8,500	$1,371,691
20	**SRFS**	$3,031,572	$1,000,000	$2,816,969	$194,427	$159,649	$34,000	$7,236,616
21	**SRFS**	$719,998	$200,000	$1,602,467	$194,427	$79,825	$8,500	$2,805,217
22	**SRFS**	$3,941,043	$800,000	$1,686,807	$194,427	$41,509	$25,500	$6,689,286
23	**SRFS**	$4,547,357	$1,200,000	$1,686,807	$388,853	$478,947	$42,500	$8,344,465
Element Totals		$28,841,109	$9,045,000	$19,833,482	$7,631,246	$3,064,736	$393,550	$68,809,123

Alternative 3

System #	*Function*	*Procurement*	*Integration*	*Logistics*	*Operational*	*Maintenance*	*Disposal*	*Total*
1	**CS**	$723,305	$500,000	$1,661,291	$291,640	$399,123	$4,250	$3,579,610
2	**CS**	$149,135	$10,000	$342,534	$194,427	$79,825	$12,750	$788,671
3	**CS**	$298,270	$100,000	$685,069	$291,640	$159,649	$17,000	$1,551,628
4	**CS**	$149,135	$500,000	$342,534	$291,640	$79,825	$12,750	$1,375,884
5	**CS**	$298,270	$25,000	$685,069	$145,820	$159,649	$12,750	$1,326,558
6	**CS**	$298,270	$75,000	$685,069	$145,820	$159,649	$12,750	$1,376,558
7	**CS**	$298,270	$25,000	$685,069	$437,460	$159,649	$12,750	$1,618,198
8	**CS**	$298,270	$75,000	$685,069	$437,460	$159,649	$12,750	$1,668,198
9	**CS**	$59,654	$35,000	$68,507	$437,460	$15,965	$12,750	$629,336
10	**CS**	$596,541	$100,000	$85,634	$97,213	$31,930	$8,500	$919,817
11	**CS**	$1,193,081	$50,000	$342,534	$0	$15,965	$1,700	$1,603,280
12	**HK**	$0	$0	$0	$1,749,840	$0	$0	$1,749,840
13	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
14	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
15	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
16	**SBS**	$0	$100,000	$0	$0	$0	$6,800	$106,800
17	**SBS**	$149,135	$600,000	$342,534	$97,213	$79,825	$8,500	$1,277,207
18	**SRFS**	$2,982,703	$1,000,000	$2,860,162	$97,213	$159,649	$34,000	$7,133,727
19	**SRFS**	$708,392	$200,000	$1,627,038	$97,213	$79,825	$8,500	$2,720,968
20	**SRFS**	$3,877,514	$800,000	$1,712,672	$97,213	$41,509	$25,500	$6,554,407
21	**SRFS**	$4,474,054	$1,200,000	$1,712,672	$194,427	$478,947	$42,500	$8,102,600
Element Totals		$16,554,000	$5,695,000	$14,523,455	$5,103,700	$2,260,631	$266,900	$44,403,686

APPENDIX E

Sensitivity Analysis

Raw Data Matrix

Evaluation Measure	Alternatives			
	ALT 1	ALT 2	ALT 3	P-3
Average Total Detection Time (hours)	18.08	18.49	30.57	16.62
Median Time to Engage (minutes)	593	80	80	214
Number of Sorties	2	2	1	29
ASW Systems Manning/Watch (w/o flight crew)	4	4	2	6.00

Decision Matrix (Orginal Global Weights)

Evaluation Measure	Global Weight	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3
Average Total Detection Time	0.40	0.54	0.55	1.00	0.45
Median Time to Engage	0.25	0.02	0.93	0.93	0.63
Number of Sorties	0.2	0.96	0.96	1.00	0.03
ASW Systems Manning/Watch (w/o flight crew)	0.15	0.36	0.36	0.64	0.00
Total Utility Score		0.47	0.70	0.93	0.34

Global Weight = 1

Evaluation Measure	Global Weight	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3
Average Percent Detected	1.00	0.54	0.55	1.00	0.45
Net-Readiness	0.00	0.02	0.93	0.93	0.63
Average Distance to Asset Upon Detection	0.00	0.96	0.96	1.00	0.03
Manning (w/o flight crew)	0.00	0.36	0.36	0.64	0.00
Total Utility Score		0.54	0.55	1.00	0.45

Evaluation Measure	Global Weight	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3
Average Percent Detected	0.00	0.54	0.55	1.00	0.45
Net-Readiness	1.00	0.02	0.93	0.93	0.63
Average Distance to Asset Upon Detection	0.00	0.96	0.96	1.00	0.03
Manning (w/o flight crew)	0.00	0.36	0.36	0.64	0.00
Total Utility Score		0.02	0.93	0.93	0.63

Evaluation Measure	Global Weight	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3
Average Percent Detected	0.00	0.54	0.55	1.00	0.45
Net-Readiness	0.00	0.02	0.93	0.93	0.63
Average Distance to Asset Upon Detection	1.00	0.96	0.96	1.00	0.03
Manning (w/o flight crew)	0.00	0.36	0.36	0.64	0.00
Total Utility Score		0.96	0.96	1.00	0.03

Evaluation Measure	Global Weight	Alternatives			
		ALT 1	ALT 2	ALT 3	P-3
Average Percent Detected	0.00	0.54	0.55	1.00	0.45
Net-Readiness	0.00	0.02	0.93	0.93	0.63
Average Distance to Asset Upon Detection	0.00	0.96	0.96	1.00	0.03
Manning (w/o flight crew)	1.00	0.36	0.36	0.64	0.00
Total Utility Score		0.36	0.36	0.64	0.00

APPENDIX F

	Alternative 1																				
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total
Procurement	$2,444,404	$6,111,010	$2,444,404	$1,222,202						$3,055,505					$3,666,606						$18,944,131
Integration		$1,343,000	$3,357,500	$1,343,000	$671,500																$6,715,000
Logistics					$920,400	$928,684	$937,042	$945,475	$953,984	$962,570	$971,233	$979,974	$988,794	$997,693	$1,006,673	$1,015,733	$1,024,874	$1,034,098	$1,043,405	$1,052,796	$15,763,429
Operational					$411,000	$419,220	$427,604	$436,156	$444,880	$453,777	$462,853	$472,110	$481,552	$491,183	$501,007	$511,027	$521,247	$416,998	$208,499	$0	$6,659,113
Maintenance					$38,310	$76,620	$108,545	$121,315	$127,700	$134,085	$140,789	$147,829	$155,220	$162,981	$171,130	$179,687	$188,671	$190,558	$95,279	$0	$2,038,719
Disposal																			$110,500	$165,750	$276,250
Total	$2,444,404	$7,454,010	$5,801,904	$2,565,202	$2,041,210	$1,424,524	$1,473,191	$1,502,947	$1,526,564	$4,605,937	$1,574,875	$1,599,913	$1,625,566	$1,651,858	$5,345,416	$1,706,446	$1,734,793	$1,641,654	$1,457,683	$1,218,546	$50,396,642

	Alternative 2																				
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total
Procurement	$3,721,433	$9,303,584	$3,721,433	$1,860,717						$4,651,792					$5,582,150						$28,841,109
Integration		$1,809,000	$4,522,500	$1,809,000	$904,500																$9,045,000
Logistics					$1,175,800	$1,184,031	$1,192,319	$1,200,665	$1,209,070	$1,217,533	$1,226,056	$1,234,638	$1,243,281	$1,251,984	$1,260,748	$1,269,573	$1,278,460	$1,287,409	$1,296,421	$1,305,496	$19,833,482
Operational					$471,000	$480,420	$490,028	$499,829	$509,826	$520,022	$530,422	$541,031	$551,852	$562,889	$574,146	$585,629	$597,342	$477,874	$238,937	$0	$7,631,246
Maintenance					$57,590	$115,180	$163,172	$182,369	$191,967	$201,565	$211,644	$222,226	$233,337	$245,004	$257,254	$270,117	$283,623	$286,459	$143,229	$0	$3,064,736
Disposal																			$157,420	$236,130	$393,550
Total	$3,721,433	$11,112,584	$8,243,933	$3,669,717	$2,608,890	$1,779,631	$1,845,519	$1,882,863	$1,910,862	$6,590,912	$1,968,122	$1,997,895	$2,028,469	$2,059,876	$7,674,298	$2,125,319	$2,159,424	$2,051,742	$1,836,007	$1,541,626	$68,809,123

	Alternative 3																				
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total
Procurement	$2,136,000	$5,340,000	$2,136,000	$1,068,000						$2,670,000					$3,204,000						$16,554,000
Integration		$1,139,000	$2,847,500	$1,139,000	$569,500																$5,695,000
Logistics					$848,000	$855,632	$863,333	$871,103	$878,943	$886,853	$894,835	$902,888	$911,014	$919,213	$927,486	$935,834	$944,256	$952,755	$961,329	$969,981	$14,523,455
Operational					$315,000	$321,300	$327,726	$334,281	$340,966	$347,785	$354,741	$361,836	$369,073	$376,454	$383,983	$391,663	$399,496	$319,597	$159,798	$0	$5,103,700
Maintenance					$42,480	$84,960	$120,360	$134,520	$141,600	$148,680	$156,114	$163,920	$172,116	$180,721	$189,758	$199,245	$209,208	$211,300	$105,650	$0	$2,260,631
Disposal																			$106,760	$160,140	$266,900
Total	$2,136,000	$6,479,000	$4,983,500	$2,207,000	$1,774,980	$1,261,892	$1,311,419	$1,339,903	$1,361,509	$4,053,319	$1,405,690	$1,428,644	$1,452,203	$1,476,389	$4,705,227	$1,526,742	$1,552,960	$1,483,651	$1,333,538	$1,130,121	$44,403,686

APPENDIX G

Alternative 1

System #	Function	Total Size (Cubic Ft)	Total Weight	Total Power	% Size (Cubic Ft)	% Weight	% Power
1	CS	2	55	275	0.25	0.10	3.09
2	CS	75	800	2000	9.22	1.39	22.46
3	CS	3	66	95	0.37	0.11	1.07
4	CS	0.3	15.9	400	0.04	0.03	4.49
5	CS	1.56	125	200	0.19	0.22	2.25
6	CS	3	15.5	165	0.37	0.03	1.85
7	CS	0	40	70	0.00	0.07	0.79
8	CS	3	80	40	0.37	0.14	0.45
9	CS	7	338	576	0.86	0.59	6.47
10	HK	74.4	4968	0	9.14	8.61	0.00
11	HK	27.5	9375	0	3.38	16.25	0.00
12	HK	10	4000	0	1.23	6.93	0.00
13	HK	27.3	820	500	3.36	1.42	5.61
14	SBS	270	15660	0	33.19	27.14	0.00
15	SBS	108	8424	0	13.27	14.60	0.00
16	SBS	81	5508	0	9.96	9.55	0.00
17	SBS	81	5832	0	9.96	10.11	0.00
18	SBS	3.3	60	254	0.41	0.10	2.85
19	SRFS	7.5	408	3991	0.92	0.71	44.81
20	SRFS	0.5	23	200	0.06	0.04	2.25
21	SRFS	5.2	190	100	0.64	0.33	1.12
22	SRFS	23	900	40	2.83	1.56	0.45
	System Totals	813.56	57703.4	8906	100	100	100

Alternative 2

System #	Function	Total Size (Cubic Ft)	Total Weight	Total Power	% Size (Cubic Ft)	% Weight	% Power
1	CS	75	800	2000	9.83	1.49	21.26
2	CS	1.3	30	40	0.17	0.06	0.43
3	CS	3	66	95	0.39	0.12	1.01
4	CS	0.3	15.9	400	0.04	0.03	4.25
5	CS	1.56	125	200	0.20	0.23	2.13
6	CS	3	15.5	165	0.39	0.03	1.75
7	CS	0	40	70	0.00	0.07	0.74
8	CS	3	80	40	0.39	0.15	0.43
9	CS	7	338	576	0.92	0.63	6.12
10	HK	0	0	0	0.00	0.00	0.00
11	SBS	0	2400	506.7	0.00	4.46	5.39
12	SBS	68	10055.3	516	8.91	18.70	5.48
13	SBS	21.3	600	164	2.79	1.12	1.74
14	SBS	0	2200	50	0.00	4.09	0.53
15	SBS	270	15660	0	35.39	29.12	0.00
16	SBS	108	8424	0	14.16	15.67	0.00
17	SBS	81	5508	0	10.62	10.24	0.00
18	SBS	81	5832	0	10.62	10.85	0.00
19	SBS	3.3	60	254	0.43	0.11	2.70
20	SRFS	7.5	408	3991	0.98	0.76	42.42
21	SRFS	0.5	23	200	0.07	0.04	2.13
22	SRFS	5.2	190	100	0.68	0.35	1.06
23	SRFS	23	900	40	3.01	1.67	0.43
	System Totals	762.96	53770.7	9407.7	100	100	100

Alternative 3

System #	Function	Total Size (Cubic Ft)	Total Weight	Total Power	% Size (Cubic Ft)	% Weight	% Power
1	CS	75	800	2000	11.08	2.06	23.33
2	CS	1.3	30	40	0.19	0.08	0.47
3	CS	3	66	95	0.44	0.17	1.11
4	CS	0.3	15.9	400	0.04	0.04	4.67
5	CS	1.56	125	200	0.23	0.32	2.33
6	CS	1.56	125	200	0.23	0.32	2.33
7	CS	1.56	125	200	0.23	0.32	2.33
8	CS	3	15.5	165	0.44	0.04	1.93
9	CS	0	40	70	0.00	0.10	0.82
10	CS	3	80	40	0.44	0.21	0.47
11	CS	7	338	576	1.03	0.87	6.72
12	HK	0	0	0	0.00	0.00	0.00
13	SBS	270	15660	0	39.89	40.40	0.00
14	SBS	108	8424	0	15.96	21.73	0.00
15	SBS	81	5508	0	11.97	14.21	0.00
16	SBS	81	5832	0	11.97	15.04	0.00
17	SBS	3.3	60	254	0.49	0.15	2.96
18	SRFS	7.5	408	3991	1.11	1.05	46.56
19	SRFS	0.5	23	200	0.07	0.06	2.33
20	SRFS	5.2	190	100	0.77	0.49	1.17
21	SRFS	23	900	40	3.40	2.32	0.47
	System Totals	676.78	38765.4	8571	100	100	100

APPENDIX H

Tactically Integrated Sensor (TIS)

The TIS combat system is a derivative of the aircraft Carrier Vessel—Tactical Support Center (CV-TSC) currently deployed on all U.S. aircraft carriers as an integral component in the ships defense system (SDS). The TIS system provides the Naval Expeditionary Costal Command (NECC) and Maritime Expeditions Security Force (MESF) with a common operating picture (COP) by integrating and correlating the various sensor inputs.

The HAMR ASW module will use the TIS to merge sensor information provided by acoustic sensors, RADAR, EO/IR or optical camera, and global positioning system data into a single tactical operating picture. TIS is capable of correlating track information, displaying range, speed and other target metadata, and providing potential firing solutions. It also provides a number of integrated and user definable tactical decision aids (TDA) and cannot export this information to other systems.

Operating on standard rack mounted COTS PCs, the TIS software is written in JAVA and was developed by NAVSEA Keyport. The operating system runs on a suit of COTS, ruggedized PC compliant computers and one additional PC computer running UNIX to accomplish its mapping function. An advantage to the HAMR ASW module includes the utilization of the source code at no cost. The TIS system is designed to be SOA compliant, transportable, scalable, and IA compliant and interfaces with secure communications like Link 11, 16, and ultimately Link 22 when fielded. Because TIS is able to render numerous inputs to tracks and distribute the tracks, it is well suited for an unmanned ASW alternative.

AN/USQ-119E (V) GCCS-M

The AN/USQ-119E (V) Global Command and Control System - Maritime (GCCS-M) is one of the U.S. Navy's primary command and control system for communications capabilities. GCCS-M is comprised of four main variants: ashore, afloat, tactical and mobile, and multi-level security (MLS). It uses the command, control,

communications, computers, and information (C4I) technology to support the warfighter mission needs. Tactical information will be passed to warfighters by using a secure and non-secure internet protocol router network.

Its integrated command, control, and information system provides the U.S. and allied commanders with the capability to "receive, process, display and maintain data on the readiness of neutral, friendly and hostile forces and geo-location data on friendly, hostile and neutral land, sea and air forces."[58] For the purposes of HAMR missions, it will not use the display console. The display technology will be used via the TIS system. Instead, the GCCS-M processor will be the main component needed for command and control capabilities.

Communications

One of the major functions of this ASW mission module is the combat communication systems. The communication systems considered for the HAMR module are the AN/USQ-125 Link 11, AN/URQ-107 Link 16, Link 22, AN/PRC-117 Satellite Communication (SATCOM) System, Common Data Link Class I System, AN/PRC-148 Joint Tactical Radio System (JTRS), and the Automated Digital Network System. These communication systems are critical in supporting the HAMR ASW missions. The primary purpose of these communication systems is to pass message traffic information and data to the fleet and to ensure real-time tactical information and data are available at moments needed.

AN/USQ-125 Link-11 System

The Link-11 communications system is the common tactical data link used by all U.S. Navy and allied ships to provide "high-speed, computer-to-computer exchange of digital tactical information among ships, aircraft, and shore installations."[59] The Link 11 communications system is seen in Figure 58 has the capability to operate at either high-frequency (HF) or ultra-high-frequency (UHF) radios with the switch of a button. The HF system is the long-range communications system while the UHF communications is

---

[58] Sumner [2008]
[59] "AN/USQ-125(V) Link-11/TADIL-A Data Terminal Set/Link-22 SPC" [2008]

limited to line of sight. The HF band allows the HAMR module to transmit and receive signals in all directions with coverage up to 300 NM from the transmitting site. The UHF band of the Link-11 system can transmit and receive signals in all directions with coverage up to 150 NM for ship-to-air links.

Figure 58. Link 11 System.

The AN/URQ-107 Link-16 System

The Link 16 is a digital data transmission system that broadcasts information at a high rate over the secure networks. The Link 16 system has the capability to support the exchange of data information which includes surveillance data, control data, electronic warfare data, mission tasking, weapon information, and assignments. The HAMR ASW mission module allows for command and control of combat environment providing a "real-time and jam-resistant, secure transfer of combat data, voice and relative navigation information to a variety of aircraft, ships, and other platforms that are equipped with Link-16."[60] Link 16 increases the ability of the combatant commander in maintaining situation awareness and exchanging critical targeting and threat information.

Link-22 System

Link-22 is the next-generation NATO tactical data link. It is a more economical data link communication system that is capable of replacing the aging Link-11 and can be interoperable with Link-16 networks. The Link-22 is a data link communication system which uses radio frequency media to communicate with air, surface, subsurface, and ground-based tactical forces. Its time division multiple access (TDMA) architecture

[60] "JAM-resistant Link-16 radios bring communications versatility to the battlefield." [2006]

design has proven to increase flexibility and decrease net management overheads by ten folds. It offers the dynamic TDMA protocols where “a single Link-22 participant can operate on up to four independent networks simultaneously.”[61]

The Link-22 system is not yet used by any coalition forces. The plan to replace Link-11 was determined by numerous countries, however the DoD does not plan to employ the Link-22 system in the near future. The Link-22 system is included in the system analysis, cost, and modeling incase the United States decides that it is necessary to use this technology. If U.S. armed forces decide to utilize the Link-22 technology, it will not cease using Link-11 since it is not backwards compatible.[62] Many countries will continue to use Link-11 and the need to communicate with them is imperative.

Common Data Link (CDL) Class I System

Common Data Link (CDL) Class I was considered on the HAMR ASW mission module for it will operate at an operating speed of less than Mach 2.3 with an altitude of less than 80,000 ft. CDL system has been proven to be a “better, faster, and cheaper communication system that provides seamless communications between multiple intelligence, surveillance, and reconnaissance collection systems.”[63] CDL permits the uplink, downlink, and jam resistant that captures imagery and signals intelligent and provides timely tactical data link information to the fleet.

The main advantage of CDL is its ability to upload and download information at high rates. The uplink operates at a range of 200 kbps and possibly up to 45 Mbps, while the downlink can operate at a range from 10.71 Mbps to 234 Mbps.

AN/PRC-117 SATCOM System

AN/PRC-117 is the Navy’s current satellite system and is a fully integrated with multi-band and multi-mission handheld radio communications capability. It has coverage from 30 to 512 MHz frequency spectrum and offers the most advance security and performance features demanded for the HAMR ASW mission module. AN/PRC-117 has

[61]“Command, Control, Communications, Computers, and Intelligence” [2008]
[62] Boyd [2008]
[63] “Common Data Link [CDL]” [2008]

the High Performance Waveform (HPW) which "ensures error-free data delivery using high-speed, over-the-air data rates."[64] It also has the capability for wireless radio cloning with the Radio Programming Application to ensure swift establishment of critical communications when needed.

Joint Tactical Radio System-Maritime (JTRS-M)

The Joint Tactical Radio System-Maritime (JTRS-M) is a "multi-mode, multi-band system that provides adaptive communications capability satisfying the existing and future communication waveform."[65] It satisfies both narrowband and wideband networking waveforms that include the UHF Line of Site (LOS) and Single Channel Ground and Airborne Radio System (SINCGARS), HF, VHF, and UHF SATCOM. Figure 59 shows this system.

Figure 59. JTRS System.

JTRS employs the Mobile User Objective System (MUOS) capability as a subsystem for improved ground force communications. MUOS uses narrowband tactical satellite communication technology and will replace the Ultra High Frequency Follow-On (UFO) system.

[64] Kaman [2001]
[65] "Command, Control, Communications, Computers, and Intelligence" [2008]

Automated Digital Network System (ADNS)

The Automated Digital Network System "provides ship and shore internet protocol (IP) connectivity, facilitating the merging of 'stove-piped' information-exchange systems and increasing the effective throughput of existing radio frequency (RF) circuits."[66] It is capable of automatically routing and switching the tactical and strategic data through the Internet Protocol networks. This network has the capability to link deployed battle groups with each other and with the Defense Information Systems Network ashore via multiple radio frequency (RF) paths. ADNS uses COTS, Non-Developmental Items (NDI), Joint Tactical Architecture (JTA)-compliant hardware (routers, processors, and switches), and commercial-compliant software in a standardized, scalable, shock-qualified rack design.

ARR 970 Sonobuoy Receivers

The ARR 970 is a 64 acoustic channel sonobuoy receiver system with 64 simultaneous receivers. It is a highly capable receiver with 99 standard RF channels allowing for a total of 495 sub-channels. The fully modularized system consists of three modules: the R-624(V)1, R-624(V)2 and the radio frequency distribution (RFD) unit. The difference between the R-624(V)1 module and the R-624(V)2 module is that the R-624(V)1 provides the sonobuoy position system (SPS) while the V2 does not. Both R-624 modules each have 32 acoustic signal processing channels allowing for a combined 64 channel receiver for the entire ARR 970 system. The picture of the system is shown in Figure 60. The fully modular design of the ARR 970 gives the operator flexibility due to the interchangeable modules. This makes the system "logistics friendly" in cases of failures and other maintenance issues.

[66] "Command, Control, Communications, Computers, and Intelligence" [2008]

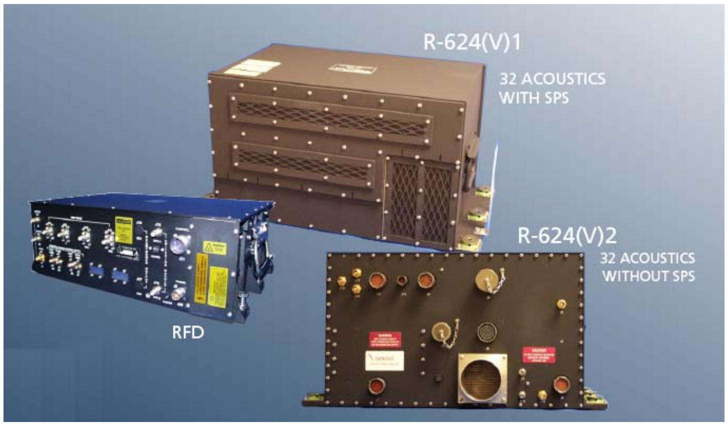


Figure 60. Three Subsystem Modules.

Integrated Sonobuoy Launching Management System (ISLMS)

The integrated sonobuoy launching and management system ISLMS, is designed by NUWC Keyport. It utilizes multiple cannibalized P-3 sonobuoy racks and integrates a launcher design and operates by a single rack COTS IBM compatible computer. The ISLMS is integrated with a GPS and TIS mapping component to provide an on screen display. The operator will locally or remotely create a pattern by selecting from a library of pre-established buoy patterns or templates to overlay in the existing environment. As the delivery platform flies over the targeted area, the ISLMS system will dispense the buoys from the ASW module to the operator's choice of pattern. This allows the types and modes of the buoys to be entered into the system providing unattended placement of type and frequency specific buoys desired by the operator.

Sonobuoys

One of the primary ASW detecting, localizing, identifying, and tracking systems that the HAMR will deploy is the sonobuoy. It can be produced in large quantities for deployment and are relatively cheap to manufacture because they are expendable non-repairable. The HAMR will not require maintenance actions to be performed at the organizational, intermediate, or depot maintenance. All sonobuoys are heavily reliable in operation and are able to transmit information back to the aircraft for processing and display with a rapid response time. The HAMR will use 30 internal racks on alternatives

1 and 2 and 60 internal racks on Alternative 3 to hold up to 36 sonobuoys on each rack for a total of 1080 and 2160 sonobuoys respectively.

The HAMR will deploy four basic types of sonobuoys; passive, active, special purpose, and extended echo ranging (EER). Passive sonobuoys detect noises from submarines. Active sonobuoys detect acoustic pulses (echos) bounced off submarine hulls. Special purpose sonobuoys are used to measure the ocean water temperature profile or to communicate with submarines.[67] EER uses energy pulses to retrieve acoustic data that is reflected off of a source. Figure 61 shows a drawing of the newer sonobuoys styles.

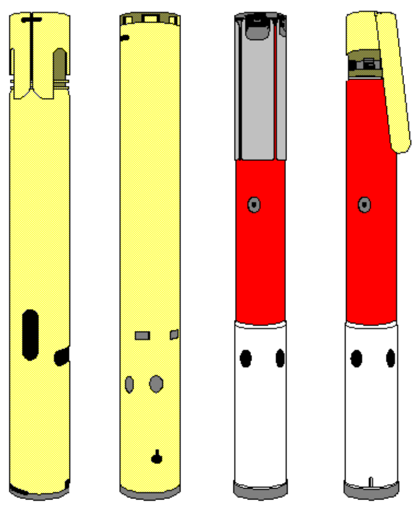


Figure 61. Sketch of Various Sonobuoys.

AN/SSQ-53 DIFAR Series Sonobuoy

The AN/SSQ-53 series is the Navy's premier passive sonobuoy. The receiver uses Directional Frequency and Recording (DIFAR) for listening to determine the bearings associated to underwater sounds. The sonobuoy will wait for any noise and at that point acoustic information will then be transmitted to the HAMR so that it may be processed. Fields, with at least two sonobuoys, are set up to triangulate submarines.

[67] NSWC Crane [2008]

Because it does not transmit signals through the water, the ASW threat will be unaware of the DIFAR sonobuoys.

AN/SSQ-62E DICASS Series Sonobuoy

The AN/SSQ-62E series is the Navy's premier active sonobuoy. The transmitter and receiver will use the Directional Command Activated Sonobuoy System (DICASS) in junction with a UHF downlink radio. An acoustic pulse is transmitted from the sonobuoy, by using a ping, and then reflected off any obstructions in its path for detection. Reflections from the transmitted signal will be sent back to the HAMR.

AN/SSQ-101 ADAR Series Sonobuoy

The AN/SSQ-101 series is the Navy's special purpose sonobuoy. It uses Air Deployable Active Receiver (ADAR) technology to advance transmitting and receiving tactics. The ADAR system is an acoustic data receiver that is capable of beamforming. Transmission of received real-time acoustic signals will be returned to the HAMR in a rapid response time. Some features of the ADAR sonobuoy includes a horizontal planar array sensor, horizontal aligned hydrophones, the use of 40 precisely fixed hydrophones, and the capability to receive active echoes reflecting off submarine hulls. The ADAR can significantly help ASW forces in detecting submarines operating in both shallow and deep water while rejecting spurious non-submarine related reflections.

AN/SSQ-110/A Extended Echo Ranging Sonobuoy

The AN/SSQ-110 sonobuoy will be deployed from the HAMR to approximately fifteen to twenty feet below the surface. It will then transmit a signal via VHF back to the HAMR on a pre-assigned RF channel to indicate a successful launch.[68] Once the sonobuoy is in the water it will transmit "an acoustic energy pulse until it is reflected off natural and man-made objects. When it strikes the hull of a submarine, the pulse forms

[68] NSWC Crane [2008]

an echo which is detected by a passive receiving sonobuoy. The EER sonobuoy provides long-range, active detection of submarines."[69]

MAD (Magnetic Anomaly Detection)

Submarines act like large magnets, and its magnetic field causes a localized change in the Earth's magnetic field, which can be measured by MAD. The AN/ASQ-233 system for MAD is seen in Figure 62 and consists of three subsystems: a computer power supply, control display, and a sensor. In order to use this system, the sensor must be towed below the HAMR to avoid noise due to magnetic interference. The recommended towing length is approximately 250 feet below the HAMR.

Figure 62. Subsystems within MAD.

Systems such as the SH-60B aircraft with ASQ-81 systems currently use a non-magnetic tow body which is towed away to escape the magnetic noise from the aircraft.[70] This is the same approach taken in dealing with the HAMR aircraft. However, "current state of the art towing reels, tow cables, and tow bodies designed for the AN/ASQ-233

[69] NSWC Crane [2008]
[70] Kuhlman [2008]

magnetometer are too large, too heavy and too unstable…"[71] The goal is to create a towing system that meets the proper requirements as well as the MAD's performance specifications in order to properly detect threats.

ALQ-217 Electronic Support Measures (ESM) System

The ALQ 217 ESM system was considered necessary on the HAMR module for use to passively detect "friend or foe" radar systems and transmit precise targeting tactical picture over to command centers for aid in decision making. The system consists of one receiver processor unit with active front-end amplifiers and four antenna arrays as illustrated in Figure 63. The system has a high mean-time-between-failure (MTBF) rate of over 2000 hours reliability in littoral environment performance. The module "employs open systems architecture (VME) and COTS processing to ensure additional long-term supportability and growth."[72] With the five available spare slots for future the scalable receiver processor unit requires modifications. The receiver has selectable wide, medium, narrow bandwidth for full frequency range coverage. Proven military digital receiver COTS technology is incorporated to add security and increased performance.

---

[71] McGovern [2008]
[72] Owego [2008]

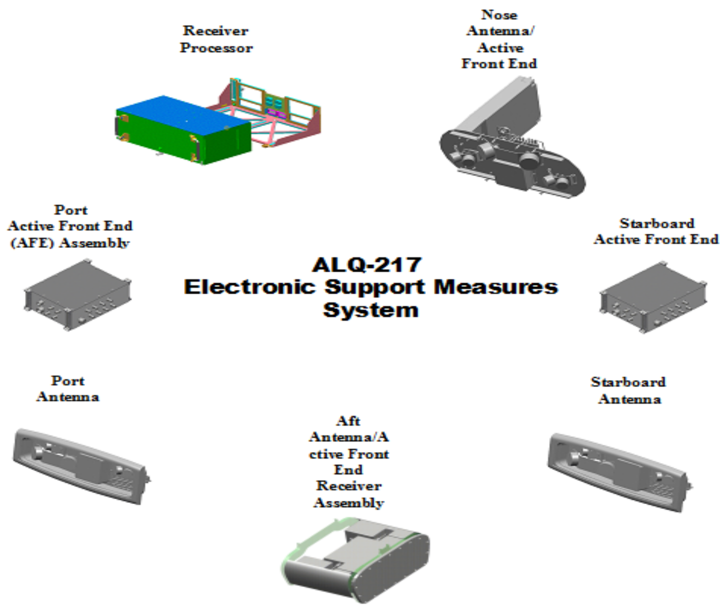


Figure 63. Entire EMS System.

AN/APY-10 RADAR

The AN/APY-10 RADAR system shown in Figure 64 is a multi-mission maritime and overland surveillance RADAR. It is capable of performing long-range surface search and target tracking, periscope detection, ship imaging and classification using synthetic aperture radar and inverse synthetic aperture radar. This next generation radar system has high mean-time-between-failure of 475 hours video outputs/interfaces and a color weather mode capable of detecting in all weather conditions. The performance of the maritime target detection capability has a RADAR cross section ranging from 1 to 10,000 square meters at 29 to 200 nautical miles.

Figure 64. APY-10 RADAR System.

Electro Optical / Infrared (EO/IR) Imaging Sensor

Electro-optics (EO) is a branch of technology of the generation, modulation, detection and measurement, or display of optical radiation by electrical means. The term "Electro-optic" in its popular definition is often used mistakenly as a synonym for the sub-fields of optoelectronics and photonics. Optoelectronics is the study and application of electronic devices that source, detect and control light, usually considered a sub-field of photonics. Photonics is the science of generating, controlling, and detecting photons, particularly in the visible and near infra-red (IR) spectrum. For the purposes of this paper the team followed the popular definition of "EO/IR" system to be defined as a sensor system that converts photons in the visible and infrared spectrum into electrical signals.

The HAMR team decided that it may be useful for the HAMR ASW module to have an EO/IR imaging capability to help increase the probability of visual detection of a submarine periscope or surfaced submarine. In addition the EO/IR imaging sensor would also provide improved intelligence and surveillance capability. The HAMR team investigated current EO/IR systems in use by militaries using open source resources. The team opted to further research the imaging system suites from FLIR Systems Inc. as they are the market leader for EO/IR systems.

A representative from FLIR systems recommended the AN/AAQ-21 Star SAFIRE III system as an appropriate candidate for the HAMR ASW module research project. The StarFire III is a high resolution camera that eliminates the need for visual detection. The Star SAFIRE III is currently used onboard multiple airborne platforms

(particular platforms that are classified), and should give an appropriate representation of an EO/IR imaging system for the HAMR ASW module. The Star SAFIRE III consists of an IR Imager, and several optional payloads including: Color Zoom Camera, Spotter Scope, Low-Light Camera, and Laser Rangefinder. Figure 65 shows part of the SAFIRE III System.

Figure 65. Image of Star Safire III EO/IR System.

The major advantage of Star Safire III is the capability to detect a floating wire antenna or communications buoy attached to an ASW threat that is near periscope depth. Other capabilities include detection of a change in temperature of the water, gas emissions from a diesel powered submarine or cavitations.

LIDAR (light detection and ranging)

Airborne LIDAR is a means of tracking enemy threats and can be implemented on the HAMR. Essentially, a laser pulse from the sensor pod penetrates through the water in order to detect the threat. A unique concept of LIDAR is the use of its receivers which provide both 2-D and 3-D images of the water column. "The combination of these receivers has the sensitivity and range resolution to discriminate the submarine's multiple signatures from noise and the many degrading optical effects of sea water and waves."[73]

An upgrade to the LIDAR is the April Showers Upgrade. The April Showers Upgrade contains five sections as shown below in Figure 66. Although each section

[73] Kaman [2008]

serves its own, important function, the receiver section contains the vast portion of what the LIDAR can do. In essence, the receiver section uses two cameras: the intensified charge-coupled device (ICCD) and the imaging time resolved receiver (ITRR).

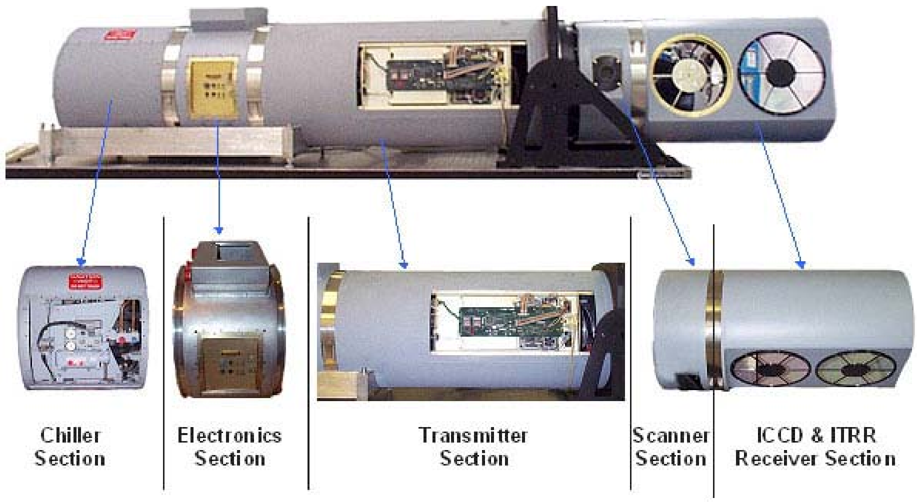


Figure 66. April Showers Upgrade LIDAR.

The ICCD detects targets in the littorals as well as classifies them. The ITRR is the 3-D camera referred to earlier. The key to the LIDAR's success is the amount of hull reflection. Even though the hull does not reflect very much, enough laser light will be reflected to create a flash picture in the receivers.

INITIAL DISTRIBUTION LIST

1. CAPT Jonathan A. Dowell, USN
   Commanding Officer
   NUWC Division Keyport
   610 Dowell Street
   Keyport, WA 98345-7610

2. Defense Technical Information Center
   Ft. Belvoir, Virginia

3. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA

4. David Allocca
   PMA-264
   22581 Saufley Rd
   Bldg 3258
   Patuxent River, MD 20670-1547

5. Donald Statter
   PMA-264D1E
   48110 Shaw Road Unit 5
   Bldg 2187 Suite 3120-C3
   Patuxent River, MD 20670

6. Stephen Huett
   NAVAIR
   47123 Buse Rd
   Build 3261
   Patuxent River, MD 20687

7. Steven Kern
   COMNAVAIRSYSCOM
   2187 NAS Patuxent River
   Patuxent River, MD 20670

8. C.E. Myers, Jr.
   President
   Aerocounsel, Inc.
   14560 Madison Run Road
   Gordonsville, VA 22942

9. Michael O'Neal
SEA 05
1333 Isaac Hull Ave
Building 197
Washington Navy Yard, DC 20376

10. Scott Rarig
KPWA 40F
610 Dowell Street
Building 1050
Keyport, WA 98345-7610

11. Timothy Busch
KPWA CAG
CMR 480 box 2466
APO AE 09128